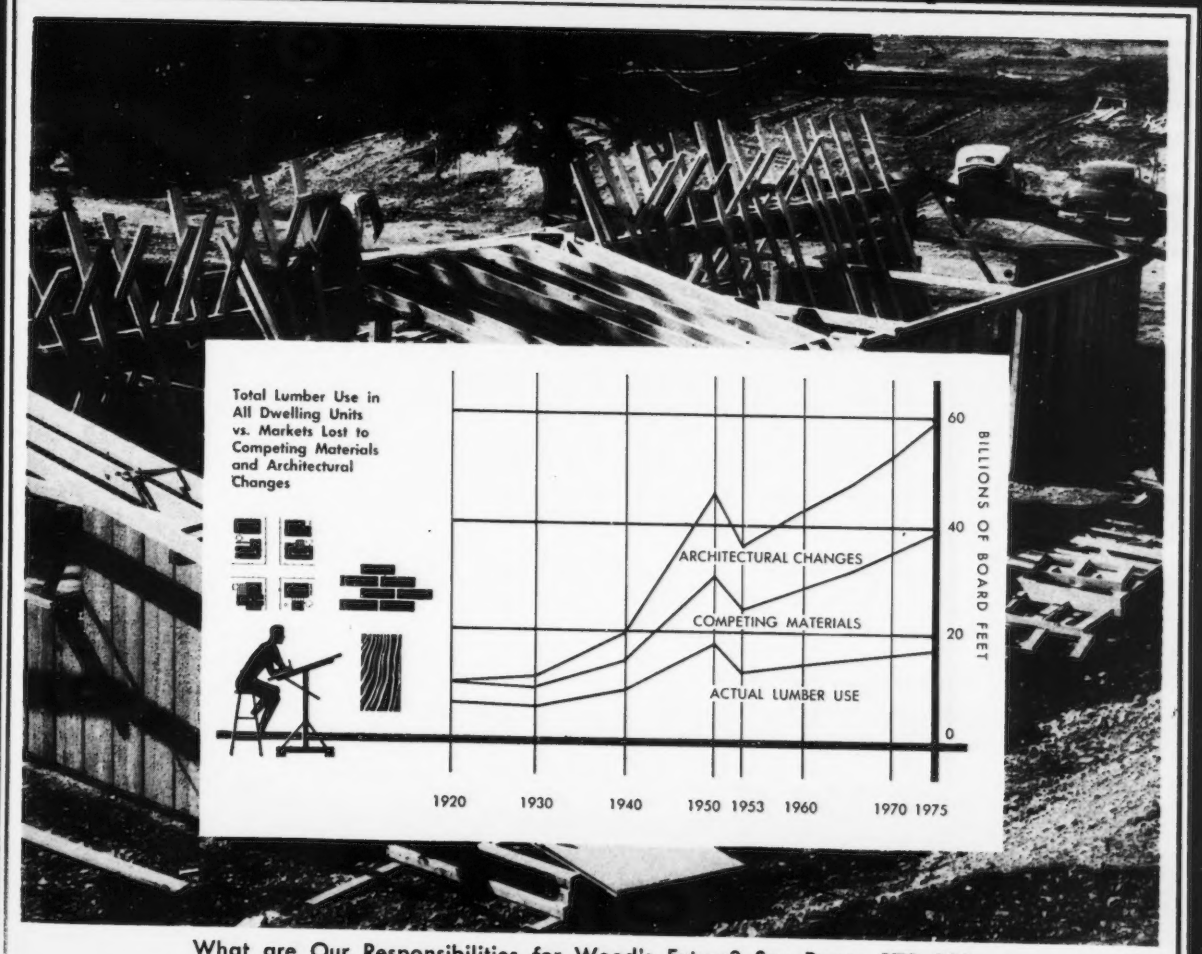
Journal of the Forest Products Research Society



What are Our Responsibilities for Wood's Future? See Pages 379–383

Published by the FOREST PRODUCTS RESEARCH SOCIETY BOX 2010, MADISON 5, WISCONSIN

"We have used Melurac® 300 for Six Years for laminating veneers of our molded plywood boat hulls"

—reports Mr. Carlton H. Foster, *President*
Dunphy Boat Corp., Oshkosh, Wis.

Here is Mr. Foster's voluntary statement in full:

"After exhaustive tests with various resin bonds, the Dunphy Boat Corporation has for the past six years used MELURAC 300 powdered melamine-urea-formaldehyde resin for the lamination of the veneers in the bag-molding production of molded plywood boat hulls.

"We continue to use this adhesive exclusively for various reasons, the first naturally being that it produces a bond of complete durability when exposed to the extreme climatic conditions found not only in the United States, but also in Alaska and the tropics of Central and South America, and in both fresh and salt water.

"While durability of the adhesive is the paramount prerequisite for a bonding resin, other factors that influenced our choice were MELURAC's dependability in preparation, excellent shop life, ease of handling through the spreaders, elimination of resin stain, and lessening of dermatitis in handling."

Like to know more about the advantages of MELURAC 300? Write today. Our sales engineers will be glad to consult with you about *your* application. Samples available for evaluation under your own test conditions.

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PLASTICS AND RESINS DIVISION
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USERS OF SAP STAIN CONTROL CHEMICALS:

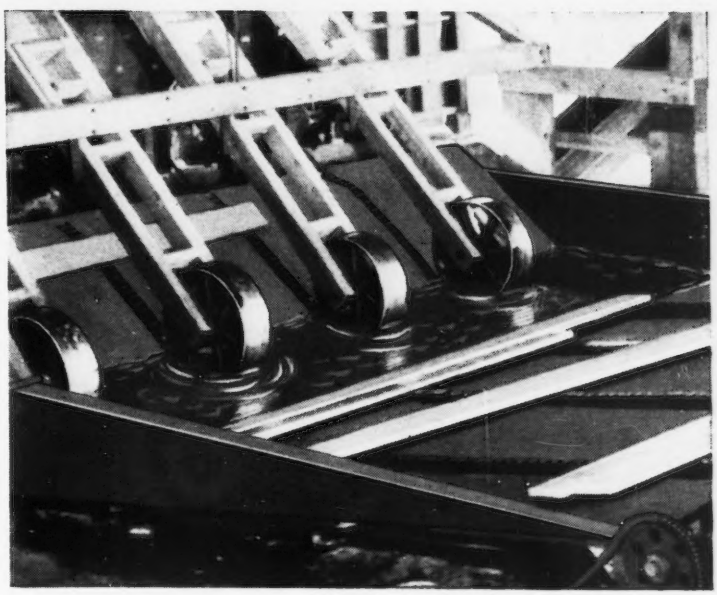
No irritating dust problem with Permatox 10-S

New ingredient makes Permatox 10-S easier to handle and mix than ever before

Since 1933 Chapman has conducted continuous research to improve sap stain chemicals and methods of application. The newest Chapman research development in this field makes Permatox 10-S practically dust-free by the addition of a new ingredient to this tried-and-proven formula.

There is no increase in price for this improved Permatox 10-S.

Permatox 10-S prevents *both* sap stain and mold in hardwoods and softwoods. Mixed with Chapman Ambrocide, it also protects lumber against damaging attacks by ambrosia beetles and other insects.



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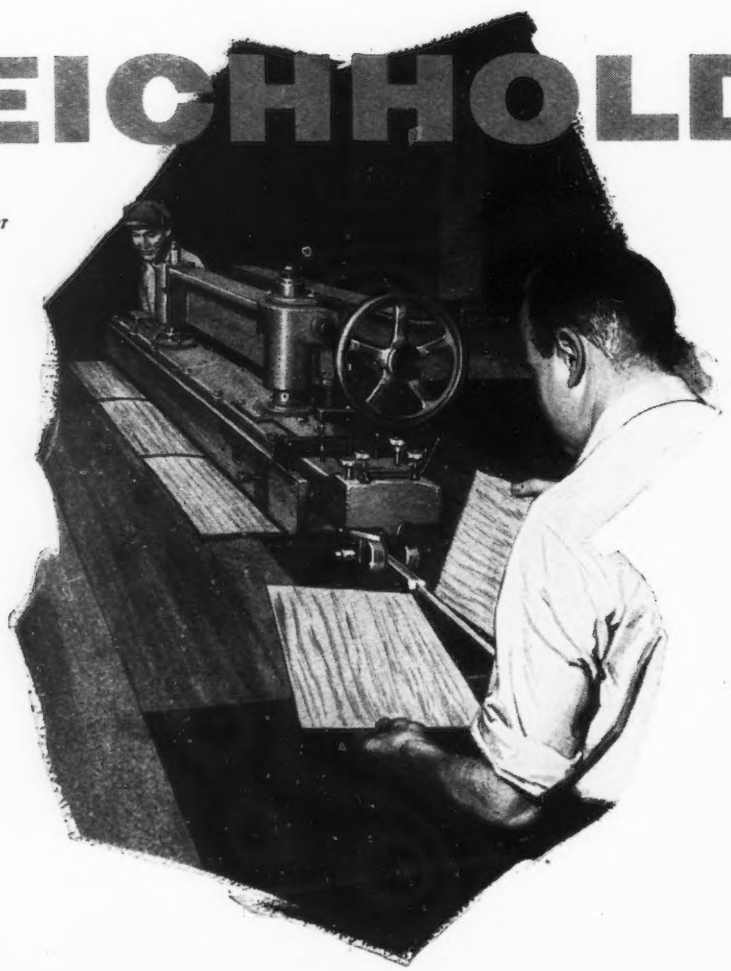
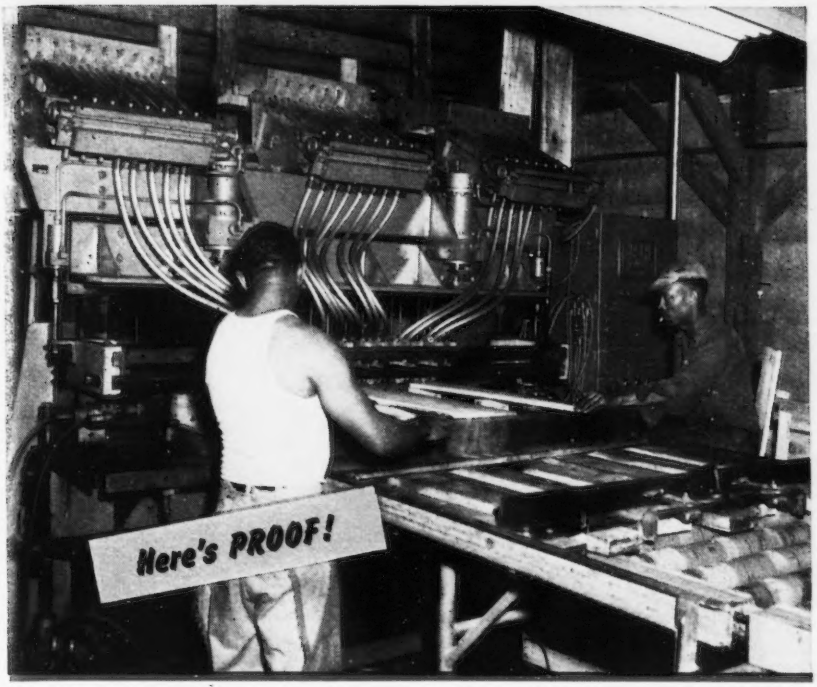
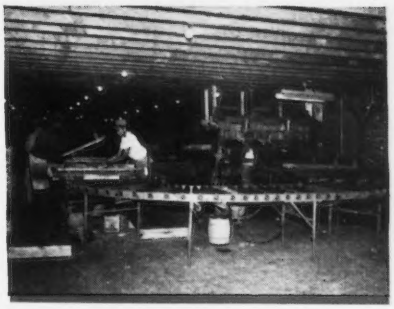


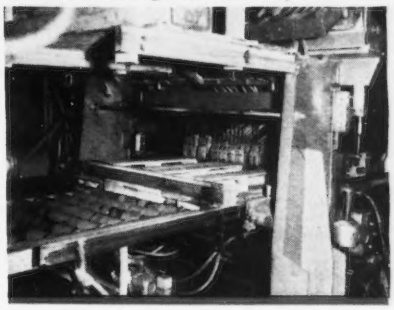
Synthetic Resins
Chemical Colors
Phenol
Glycerine
Phthalic Anhydride
Maleic Anhydride
Sodium Sulfate
Sodium Sulfite



Front view of new Diehl Model #720 HYDRONIC Nailer, in operation at Arkansas Pallet Company. With fully automatic features, HYDRONIC has stepped up pallet production to 800 pallets a day.



Using powered conveyor set in circle through the HYDRONIC, nine men are kept busy loading and unloading. Tenth man is operator.



Back-view of new Diehl HYDRONIC, showing open-back design which permits straight-through feeding, eliminating work-and-turn.

New Diehl Hydronic® Nailer

reduces time and labor costs up to 50%

As one of the Nation's biggest producers of quality, low-cost pallets, Arkansas Pallet Company of Pine Bluff, Ark., is constantly looking for *faster, better, lower-cost automatic nailing.*

And as the photos above indicate, Arkansas Pallet has *found* it . . . with the new Diehl HYDRONIC Nailer, which combines automatic Electric Control and Hydraulic Power.

After only six weeks of operation, here is Arkansas Pallet's report on their new Model 720 HYDRONIC: (1) Production has increased substantially, using seasoned oak, driving 14 to 24 nails per stroke with up to 2½" drive-screw nails. (2) Pre-drilling is *eliminated,* yet board-splitting is *much* less than before. (3) Nail-wastage is *also* reduced. (4) Output is up to 800 pallets per day!

With the new HYDRONIC, Arkansas Pallet is now able to have a *conveyorized* operation . . . nine men are used to load and unload the HYDRONIC, with a tenth man as operator.

Management opinion? Owners Robin Jordan and Donald Drake say "We're *sold* . . . this machine has the features we *needed* . . . and once personnel are completely familiarized with the new operation, we expect production to hit 1000 pallets a day!"

It will pay *you, too,* to *investigate* the new Diehl HYDRONIC Nailer—to get full *details* on its Electric Master Control Panel that selects nailing combinations, adjusts the table, and actuates the clinching bar and nail hoppers *at the flick of switches* . . . plus the HYDRONIC's smooth, steady Hydraulic Power that *pushes* nails through the wood, *eliminating* pre-drilling and *minimizing* nail-bending and contour driving . . . features that add up to *mass-production* of boxes, pallets, skids, reels, *at less cost per unit with better quality.*

Write to Diehl today—ask for the new HYDRONIC Nailer Bulletin, No. N-454!

Standard of Comparison in the Woodworking Industry

THE G. M.

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MACHINE WORKS, INC.

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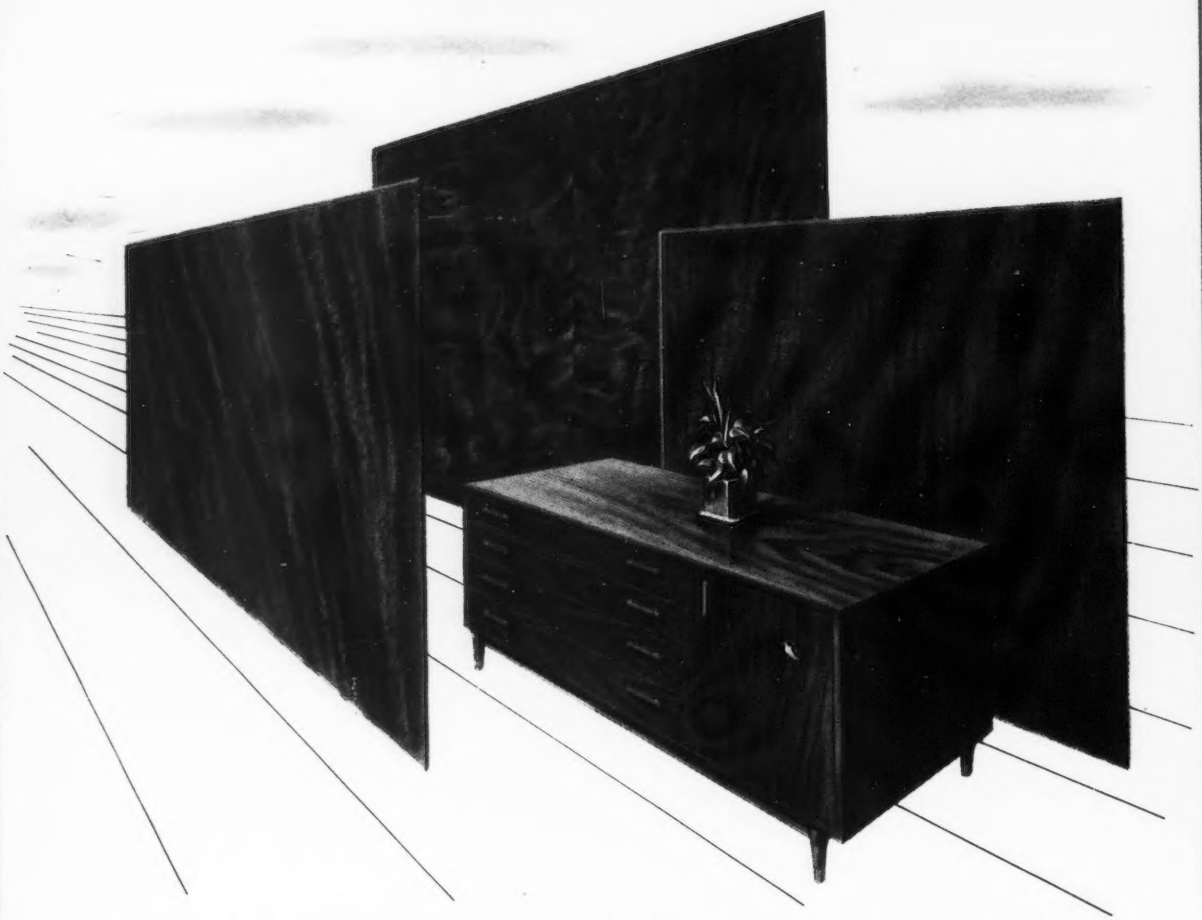

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JOURNAL OF THE FOREST PRODUCTS RESEARCH SOCIETY

Vol. IV, No. 6 December, 1954

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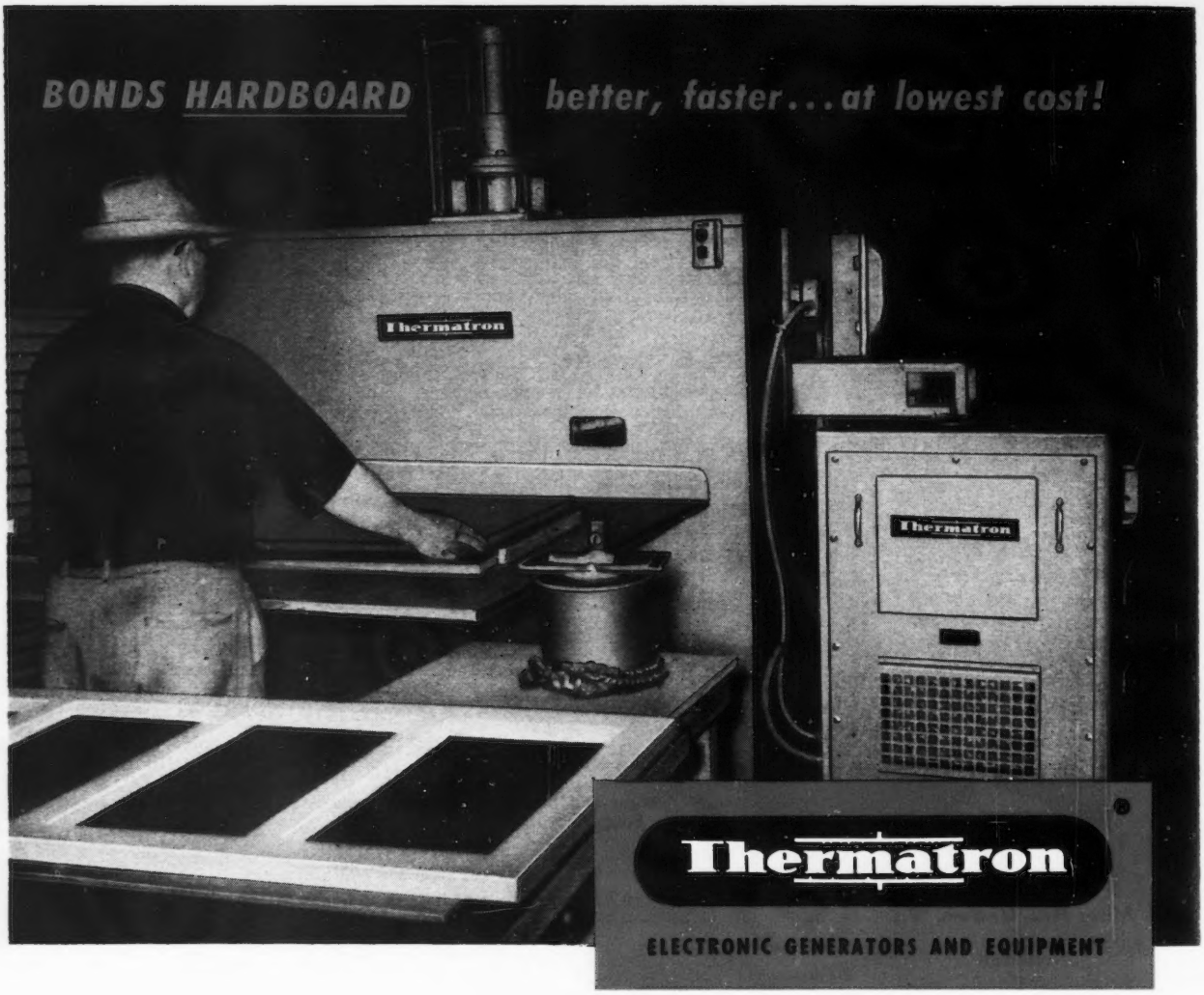
This attractive green and gold FPRS lapel pin is now available. It will identify you as an active supporter of Wood industry research and progress. Simply send 75 cents to Executive Secretary, P. O. Drawer 2010, University Station, Madison 5, Wis. or send $1 and also receive framable FPRS wall certificate.



Tempered hardboard can be successfully bonded with THERMATRON electronic generators and hydraulic presses—combining the best, fastest and most inexpensive method of gluing with the best and cheapest wood-material on the market today! The variety of products is practically limitless with new uses being discovered daily . . . from radio and TV cabinets, furniture and displays *to houses and even vehicles!*

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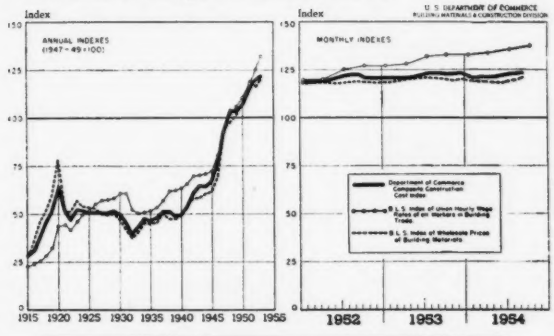
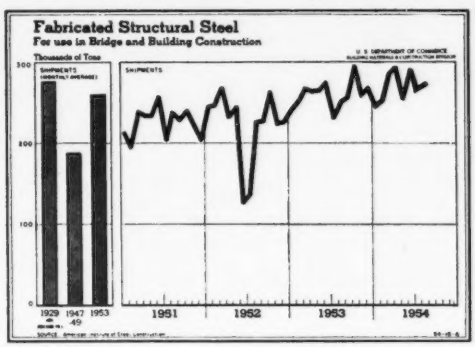
FPRS NEWS-DIGEST

Volume 4 DECEMBER, 1954 Number 12

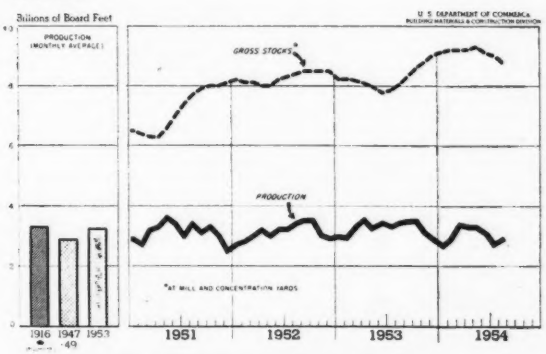
GRAPHIC TRENDS

Construction Costs-Building Materials Prices-Union Wage Rates, 1915-1954





Lumber



SWING TO MORE RESEARCH in wood industry is reflected by a 41% increase in research projects in first 10 months of '54 at Timber Engineering Co., NLMA research affiliate, Washington, D. C. Also, total research being conducted for trade associations has doubled in volume over '53.

—TECO

BUSINESS OUTLOOK

SECRETARY WEEKS ON BUSINESS PROSPECTS: Not only has construction activity sustained earlier forecasts, but economic conditions from a broader aspect are expected to be further aided by numerous measures such as changes in tax structure, and public roads programs.

CONSTRUCTION OUTLOOK: 1954 construction will reach $37 billion and in '55, $39½ billion. Adding expenditures for modernization, repairs, renovation rebuilding, of $14 billion, a total volume of $55 billion may be anticipated, thus keeping construction the largest single industry in U. S. Reasons behind estimates: 1) confidence in administration; 2) Its fiscal and legislative policy with particular reference to the 1954 Housing Act; 3) Record population growth, 50,000 a week; one new consumer every 12 seconds; 4) Advances in technology, enhancing development of new products; 5) Backlogs of homes, schools, hospitals and highways.

—U. S. Dept. Commerce

LUMBER PRODUCTION for '54 is expected to be 5% below '53 which is estimated at 39 billion board feet. Consumption, including exports, imports and changes in distributors' stocks is figured at 39 billion board feet for '54, compared to 40 billion in '53.

NLMA

NEW IMPETUS TO SALES of home woodworking tools is being given through "education demonstration schools" throughout country. Manufacturers and dealers are turning to the "selling-by-teaching" technique and dealers report sales increases from 5 to 35%.

—Business Week, Dec. 11

AT THE JOHN WIDDICOMB CO. OF GRAND RAPIDS

Chairs and extension table are graceful and light in construction, yet built for lasting beauty. Dowel joints are permanently bonded with WOOD-LOK, National's cold run, ready-for-use resin glue.

Strength for Modern Simplicity comes from WOOD-LOK

WOOD-LOK produces handling bonds in as little as 15 minutes. It is used for doweling, blocking and gluing, mortise and tenon.

WOOD-LOK prevents chilled joints by allowing 5-7 minutes open assembly time. Production is speeded by automatic air pressure case clamp.

WOOD-LOK simplifies gluing of doweled butts and all other joints. It stays fluid in National's one-pint squeeze-applicator for fast, uniform spreading.

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WOOD-LOK vinyl co-polymer emulsion maintains maximum strength in dowel joints—as established by independent researchers.

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FPRS News-Digest, Continued

INDUSTRY NEWS

Ford Motor Co. Donates Lumber Community

Allen W. Merrell, Ford Fund vice president, announced the gift of the community of Alberta, Mich., its well-equipped sawmill, and 5.3 million feet of standing timber on 1700 adjacent acres, to the Michigan College of Mining and Technology. Accepting the gift on behalf of Michigan Tech, Grover C. Dillman, president of the college, said the Alberta properties would be used to expand Michigan Tech's forestry department facilities and its program of forest products research. To be called the "Ford Forestry Center of the Michigan College of Mining and Technology," Alberta was developed by the late Henry Ford as a model lumbering settlement.

L. J. Carr New Chairman Of NLMA Committee

L. J. Carr, L. J. Carr & Co., Sacramento, Calif., and FPRS President, was elected chairman of the Building Codes and Trade Promotion Committee, at the 1954 annual meeting of the National Lumber Manufacturers Association, Nov. 8–10, at Washington, D. C. Other members of the committee are Earl Houston, Longview, Wash.; C. D. Dosker, Louisville, Ky.; Robert S. Douglas, St. Paul, Minn.; S. B. Fullerton, Warren, Ark.; A. E. Swanke, Tigerton, Wis.; C. H. White, Chicago; Joseph L. Noyes, Marion, N. C.; Robert P. Thompson, Philadelphia; Charles E. Close, Chicago; L. M. Clady, Chicago; W. W. Miller, Jr., Johnson City, Tenn.; H. A. Hanlon, Odessa, N. Y.; P. C. Christiansen, Phelps, Wis.; J. A. Mathieu, Rainy Lake, Ontario; Alvin H. Huss, Chicago; W. W. Kellogg, Monroe, La.; T. L. L. Temple, III, Diboll, Tex.; and Eliot H. Jenkins, Springfield, Ore.

Research at TECO

Crosstie Committee Meeting was held at Association of American Railroads, Central Research Laboratory, Chicago, Dec. 3, to review 1954 research gains and develop a program for 1955.

3-Year Quality Control Program on floor finishes for use on hard maple gym and similar type floors was authorized by Maple Flooring Mfgrs. Assoc. Plans will include revision in existing MFMA specifications. Program expected to get underway in mid-1955.

6th Edition "Forest Products Research Guide," authorized by NLMA Products and Research Committee, will be published mid-1955. Will list research projects conducted by nearly 3,000 domestic and foreign organizations. Will be available at $15 per copy.

"This is TECO" new booklet, describes effectiveness of timber engineering and wood research in expanding economical utilization of our forest resources; as well as multiple activities of TECO'S services to architects, engineers, builders, and laboratory services for wood-using industries. Free, from Timber Engineering, 1319, 18th St., Washington 6, D. C.

NLMA 1955 Research Program at TECO Set Up. Members of the Hardwood Research Committee of National Lumber Manufacturers Ass'n met in November to set up a well-rounded program of research to be conducted during 1955 at TECO, NLMA's research affiliate. Research projects authorized by the committee include: the construction of a wood van-type commercial truck body, further studies of the cause and control of the red oak sap stain that is causing heavy losses in the hardwood lumber and flooring industries; continued studies of the effectiveness of Fersolin (the soil conditioner from sawdust), development of a program for broadening and increasing hardwood research, and investigations in developing new and improved processes and products for the furniture industry.

Uhl Reports. Increases of 41% in the number of private housing projects, and 23% in that of housing units, using TECO timber connectors, during the first ten months of 1954, were reported by Harry G. Uhl, pres. More than 145,000 dwelling units have been built with wood frame TECO trussed rafters, since 1946, requiring 115,000,000 bd. ft. of lumber.

SOCIETY NEWS

Inland Empire Meets Jan. 20, 21

The Inland Empire Section of the Forest Products Research Society will hold its next meeting January 20–21 at Yakima, Wash., it was announced today by Section Chairman J. H. Leuthold, pres., Deer Park Pine Industries, Deer Park, Wash. Committee meetings will be held in the afternoon, Thursday, Jan. 20, with the official dinner to be held in the evening. Friday morning, Jan. 21, there will be a business session, election of 1955 officers, and a program of technical papers presented. A tour of the Cascade Lumber Co., Yakima, will take place in the afternoon.

Industry–Education Conference

Some 42 educators, researchers, and industry representatives met at the Forest Products Laboratory, Madison, under the auspices of the FPRS Education Committee, Oct. 28, 29, to discuss curricula and greater industry opportunity for young men choosing forest products careers. The meeting was chairmaned by Alex Panshin, wood technology head, Mich. State.

The conference stressed the need for a program of broad, nation-wide dissemination of information on the importance of the forest products industries in our economy, plus probable future trends, opportunities, and salaries. Three major problems were studied.

I. *Types of training to be offered.* A starting outline of a curriculum was drawn, stressing the importance of a broad base of fundamental courses in the social and physical sciences, mathematics, and English. It was felt that professional courses might also be introduced fairly early in the 4-year program as a means of stimulating the student's interest in his chosen profession. It was recommended that a FPRS subcommittee representing education and industry be established to give further study to the development of a balanced program of basic and technical training for the major areas of specialization in the forest products field; also wherever possible forestry schools encourage students in engineering schools to take advantage of elective courses in wood technology and utilization.

II. *How to sell industry on the need.* The conference recommended that a permanent sub-committee be set up to stimulate the education of industry on the value of technically trained men. Suggestions included preparation and dissemination of information through forest products associations, companies,

(Continued on page 37-A)

IMPORTANT FPRS DATES

January 20, 21: Inland Empire Section at Yakima, Wash.

February 28: Pacific Northwest Section Meeting at Seattle, Wash.

March 14–16, 1955: Eastern Canadian Section Annual Meeting at Chateau Laurier, Ottawa.

March 17–18, 1955: Executive Board Meeting at Madison, Wis.

April 11, 12: Midwest Section at Champaign–Urbana, Ill.

April 28, 29: Northeast Section at Glens Falls, N. Y.

June 20–23, 1955: 1955 NATIONAL MEETING at Seattle,

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CONTAINING **PENTA**chlorophenol

—the quality water repellent preservative.

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Send today for the informative folder, "WOOD PRESERVATION WITH WOODLIFE", which gives test data along with suggested specifications

Protection Products
MANUFACTURING COMPANY
Since 1921
Dept. C **Kalamazoo, Michigan**

President's Column

L. J. CARR

SACRAMENTO, DEC. 15—After attending eleven FPRS Section meetings since taking office last May, it is interesting to reflect on some of my experiences. I would like to tell you about one.

As you may know I've been kidded a lot about some of my predictions on the future of the lumber industry. A few months ago an old time lumberman, and good friend of mine here in California, came up to me after one of my talks and remarked, "Les, I'm for what you say 100 percent, but I just can't go along with you on that helicopter routine." I rolled that one over and replied, "Well, Bob, you were in business 50 years ago, were you not? If someone then had made the prediction that trucks would one day take over logging from horse teams, what would you have said?" There was a slight pause, and then Bob's reply . . . "Les, I think you've got something there."

I sincerely believe that the entire future of our industry lies in the developments we are going to make in processes and products from here on out. For one, I am glad to see the thinking of the industry changing so rapidly, from self sufficiency to keen competitiveness. And I believe that as younger men coming along take over the management reins that they are going to do the kind of job that's needed, calling upon fundamental, applied, and market research as their principal tools. A great many dollars are lost each year in our industry because we do not recognize early enough the need for effective research and promotion. Timing is all-important. An example is the wood sawn shook box industry, with which I am associated here in the West.

For years we had enjoyed a healthy industry, until the fiber container came into the picture, representing a tremendous loss to lumber but no loss to forest products. In short order we lost our lemon crate market and some 50% of our lettuce crate business. We do have a new orange crate on the horizon. To illustrate the extent of this loss, these fiber cartons resulted in a net saving in freight cost alone as much as $165 a carload, and shipments ran into hundreds of carloads evety night of the year. Thus, competition drove the prices of sawn shook down $3 per thousand or some $1,500,000 a year. It was not until a year ago that our industry sufficiently realized the gravity of its position to invest the modest sum of $55,000, in the face of a million and a half dollar loss, into additional product development and promotional expense.

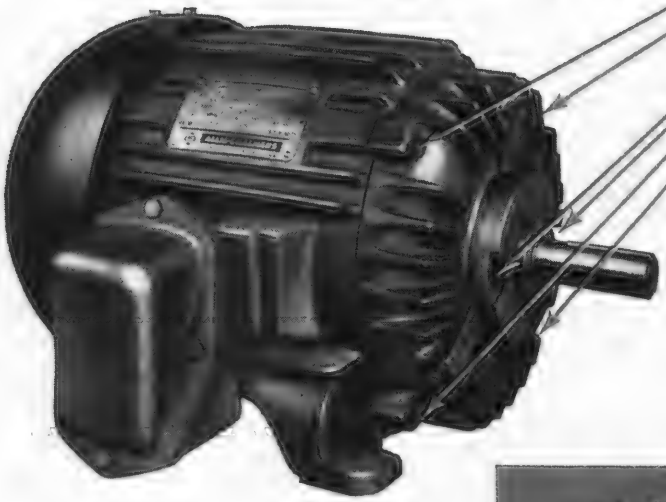
The point is that the wood industry needs not only to recognize the need for such expenditures, but also to provide a high enough percentage of the sales dollar for research and promotion. We have just reached the place where such industries as petroleum and meat packing have made their fortunes. If we will but set our sights and gear our investment to the markets that can be ours in the next decade of industrial and economic expansion, I sincerely believe we will create a great new era of forest products.

May I take this opportunity to wish each and every FPRS member and friend a most prosperous new year.

—L. J. CARR, *President*

It takes Six Bolts –

not just four

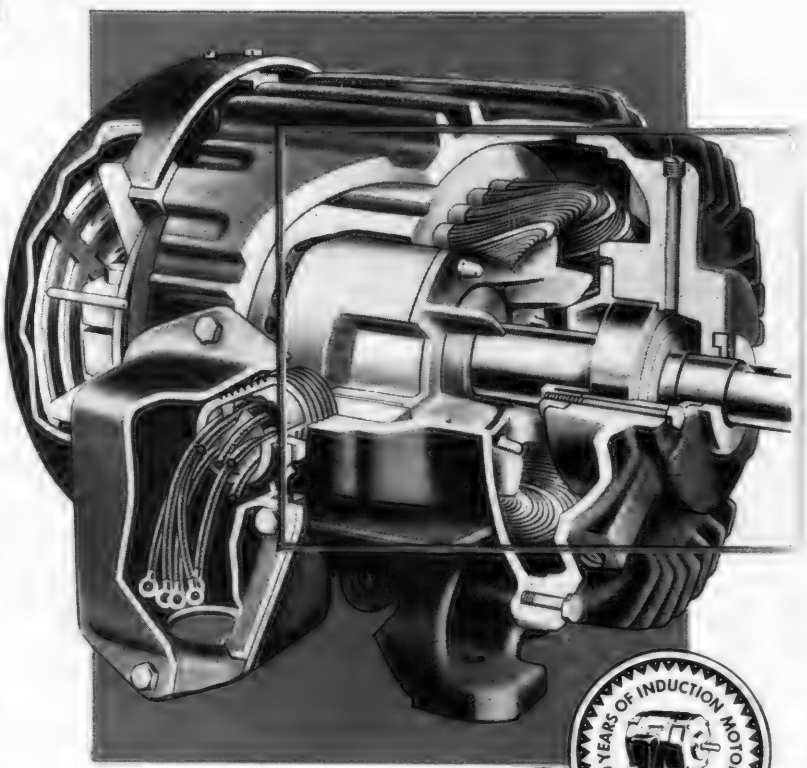


to give full bearing protection for greater motor performance

THE TWO EXTRA BOLTS in the end housing of every Allis-Chalmers ball bearing motor are the proof of *extra* protection against bearing failure. These are the bolts that hold the bearing cap tightly in place against the inner face of the bearing enclosure. This cap, with its close running clearances, keeps grease from the interior of the motor . . . retains an ample supply within the bearing enclosure . . . protects the grease and the bearing against contamination from dirt and moisture.

At the outer side of the bearing, double labyrinth seals keep grease in, also keep dirt out. What's more, large grease reservoirs act as additional dirt traps.

Result? Allis-Chalmers motors pay off in longer, trouble-free bearing life, lower motor maintenance.



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Get all the facts . . . judge for yourself — Compare Allis-Chalmers motors with other motors. Get the six-bolt construction that gives you complete bearing protection. For proof, see your Allis-Chalmers Office or Authorized Distributor, or write — Allis-Chalmers, Milwaukee 1, Wisconsin.

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The Lumber Outlook For 1955[1]

LEO V. BODINE

Executive Vice President, National Lumber Manufacturers Association, Washington, D. C.

The lumber industry can meet the challenge of competitive materials in the year ahead. Lumber manufacturers can be expected to: 1) continue to improve their product; 2) make it available at prices competitive with substitute materials; and 3) accelerate research, product publicity and merchandising programs.

PERHAPS THE BEST WAY to begin an article on lumber's prospects for the coming year is to express a personal feeling of restrained optimism—optimism over the market potentials for lumber but restraint when this is measured against the stiff competition which lumbermen will find in the market place. Here are some of the factors which will affect lumber's markets in the coming year.

The strikes that crippled sawmill and logging operations in the Douglas fir region for about three months this year raised the issue: Can the lumber industry retain its present construction markets if higher wages are imposed upon already high production costs? All the evidence points to an answer in the negative. The shutdowns also proved that we have moved completely out of a sellers' market.

Wood's competitors are working constantly to improve their products. Plastics manufacturers, for instance, are eyeing many of the construction markets held by wood and have set out to develop engineering and design data which will give a clearer indication of how plastics will perform under various conditions.

A Look at More Cheering Prospects

Lumber procurement by the Corps of Engineers, assuming continuation of the foreign aid program, should be moderately increased, from an estimated 600 million board in fiscal 1954, to about 900 million feet in fiscal 1955, increasing slightly to approximately 950 million feet in fiscal 1956.

The demand for lumber by the construction industry should continue brisk. This is one of the most significant and encouraging signs on the sales horizon, since more than 70 per cent of the lumber consumed in the U. S. goes into construction of one form or another. It seems reasonable to assume that the *total* volume of new construction in 1955 will equal and possibly exceed the peak level of 1954.

Home Building is Brightest Spot

Recent studies indicate that the average U. S. dwelling unit contains approximately 10,500 board feet of lumber. The consensus is that 1955 nonfarm housing starts will equal and perhaps exceed the 1.1 to 1.2 million figure which it appears will be recorded for 1954.

If as many as 1.35 million new dwelling units are started next year, as some have predicted, 1955 will be second only to the record-breaking year of 1950 when new starts totaled 1.396 million. Conservatively, this should mean a market for upwards of 10 billion feet of lumber.

The heavy use of wood in home construction is tied to the demand for better designed homes. The popularity of the one-story home has given builders an opportunity to show wood to its best advantage. No where are wood's fine qualities more evident than in its use for siding, paneling, ceilings and flooring.

Schools and Hospitals Important Markets

There has been an appreciable increase in the use of wood for modern one-story school buildings as contrasted to the expensive, monumental type of stone and concrete structures. Because of its strength, economy and versatility, wood has given school administrators much to work with in their efforts to whittle down the huge backlog of needed school construction. It is hoped that the trend toward wood schools will be given further impetus when our association publishes shortly the results of a comprehensive study showing how wood compares in cost with other school construction materials.

Hospital authorities have not shown as much enthusiasm as school administrators for one-story buildings. Aggressive promotion will be necessary to take advantage of this market potential.

A further and perhaps accelerated dispersal of industrial buildings may be expected in the coming year. The tendency of more and more industries to relocate away from congested areas could mean extra sales of lumber for new factories, homes, schools, stores and churches necessary to accommodate the relocating workers and their families.

Another sign which augurs well for the future is the continued improvement in the utilization of raw materials. By increasing the number of products and the volume of production from each log cut, the lumber industry can expect to retain present markets and gain some new ones which otherwise would go to competitive materials. Steady improvement along this line is showing great cumulative effect.

Furniture plants appear to be working out of the slump that plagued that industry during early 1954. Hardwoods sales for furniture manufacture and other domestic uses are expected to be better in 1955 than in 1954. Hardwoods were hit from two sides during 1954. In addition to the furniture slump, there was virtual exclusion from the British market, although importers have expressed strong preference for American hardwoods. It is hoped that strong urgings from the U. S. Departments of State and Commerce, coupled with the pleas of British importers, will cause the British government to relax its ban against U. S. hardwood imports.

Hardwood flooring demand, up 10 percent over 1953, should continue strong in 1955. The problem of the hardwood flooring manufacturers is one of disposal of low grade. In an effort to reduce this surplus flooring manufacturers are utilizing more of this material for block flooring and, to some extent, in the manufacture of low-grade prefinished strip flooring. In addition, considerable research has been done in laminating narrow widths and low-grade for heavy industrial flooring. Expanded use of low grade flooring is in prospect for the coming year. Homes on concrete slabs are a growing outlet.

Railroad purchases is another area where some improvement may be expected in the coming year. During 1953, the Class I railroads—which account for about 95 per cent of total railway mileage—bought $175.6 million of forest products, compared to $176.9 million in 1952. Another slight dip is expected in 1954.

Government to Exert Powerful Influence on Construction Industry

One activity which may spur construction of post offices and other public buildings is the lease-purchase system under which the government will pay rent to occupy privately-financed build-

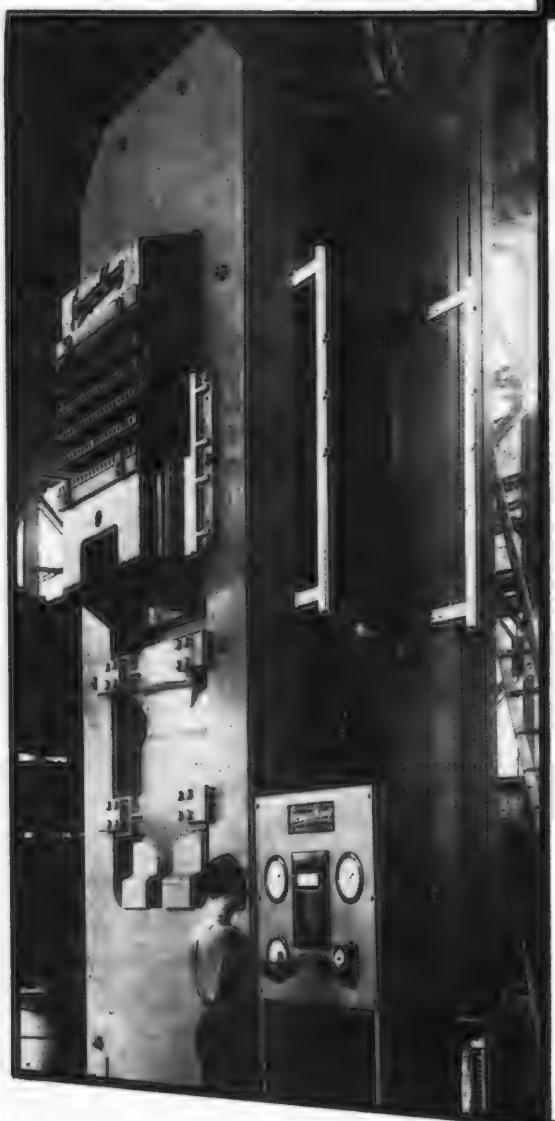
(Continued on page 18–A)

[1] A special release by N.L.M.A.

The Press to buy . . .

FOR HIGH P.S.I.

Siempelkamp



Here is a 2,000 p.s.i. Siempelkamp press with platen size of 4' x 8'.

● The advantages of one-piece frame design are becoming more widely recognized every day—particularly for presses of high p.s.i. As the leader in one-piece frame design, G. Siempelkamp & Co. builds into each press the highest degree of rigidity, simplicity and performance. Siempelkamp equipment is built in the world's largest hydraulic press plant by the world's most experienced manufacturer. Other advantages include:

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Our Responsibilities for Wood's Future[1]

C. C. HERITAGE

Director of Development, Weyerhaeuser Timber Company, Tacoma, Washington

The Stanford Research Institute study, "America's Demand for Wood, 1929–1975," emphasized the need for continually improving technology if goals of increased production and lower costs are to be achieved. In this sequel, the author points out three major areas for improvement: 1) overcoming wood performance deficiencies; 2) reduction of manufacturing costs; 3) greater utilization through manufacturing integration.

INTEREST IN THE LONG RANGE future of wood fell into disrepute during the war years and those immediately following. The order files were large, prices were more than keeping pace with rising costs, earnings were substantial, all constituting a climate in which concern for the future was not too important.

During the past year this situation has changed with rather startling rapidity. The business and technical press is replete with exhortations that technological changes are more inexorable than ever in creating and in killing markets, products and industries; that management must spend more time on long range trends.

My subject is by no means new, and if anything I have to say is new, it will be only by way of approach, like each of the three blind men describing his particular conviction relative to the appearance of the elephant. If what I say savors of preaching, it is because we are discussing a serious subject. If what I say seems critical, I hope it will also seem constructive. I shall try to provide some factual examples to delineate the present situation and hence certain of our responsibilities for wood's future.

First, a word about what is meant by wood's future. To me it is making wood provide the maximum of service to all the people, as raw material for successful business enterprises. Business success encompasses satisfied consumers, contented employees, pleased shareholders and friendly communities. The maximum of service to the people seems to me to be the production of diversified products of the highest value use consuming all the wood we can grow on our tree farms.

I want to touch on three responsibilities for the future which are of great importance. 1. Markets, uses and competition: The order file; 2. Manufacturing costs, capital investment and earnings: The economics of the business; and 3. Use of all wood grown: Manufacturing integration.

[1] Presented before a meeting of the Northern California Section, FPRS, April 24, 1954.

Markets, Uses, Competition

With respect to the first, I will confine what I have to say largely to lumber. My reason for so doing lies in my belief that the best utilization technique is an integrated one to which lumber is the key, the manufacture of lumber being the most economic means of converting forest raw material into useful products. However, there are today many examples of wood utilization without integration with lumber or plywood. These are currently justified when sawing or peeling of a particular species contributes nothing to the overall enterprise. *Abies concolor* white fir at Klamath Falls, Oregon, is going directly to the chipper for hardboard. The tree develops decay too early in its life to have put on sufficient clear wood to be as profitable for lumber as for hardboard. But that is the present situation. Is it not entirely possible that improved forest management will grow white fir in the future of such quality as to achieve a profitable lumber integration?

On the other hand, there are many examples of integrated practice, as the sulfate pulp mills and other hardboard plants of the Pacific Northwest, rapidly expanding their use of Douglas fir sawmill residuals. In the Northeast some hardwood logs for pulp are now first going to the sawmill for furniture lumber. So far as log size is concerned, there are sawmills operating successfully down to a 6″ top and a 90″ length.

It seems axiomatic that in the great majority of cases, sawmill residuals will constitute the cheapest source of wood for the non-lumber products of the future. Thus we must keep and expand our lumber markets and uses with every resource at our command.

The order file for lumber (or plywood) depends on the same merchandising principles as any other product. Product value must be attractive to the consumer, that is, performance must be in harmony with price. But price goes much farther than the original purchase and includes application, maintenance and useful life. The consumer must get his money's worth not only as judged objectively by him, but as compared with alternate materials he may use.

When we are over the hurdles of performance and price, there are the jobs of publicizing our accomplishments to establish consumer demand and preference, and finally of making it easy for the consumer to get what he wants when and where he wants it. A merchandising expert would no doubt accuse me of oversimplification but if a product has outstanding value, the consumer prefers it and it's readily available, I'd say we're in business.

In order to gauge our future responsibilities relative to lumber markets, uses and competition, what is the status quo?

First, the utility or performance of lumber is described basically by seven characteristics shown in Table I which includes also a rating for each attribute made as honestly as it is possible to do. Lumber's deficiencies are primarily in permanence and stability and to a lesser degree in uniformity and handleability. How serious are these shortcomings?

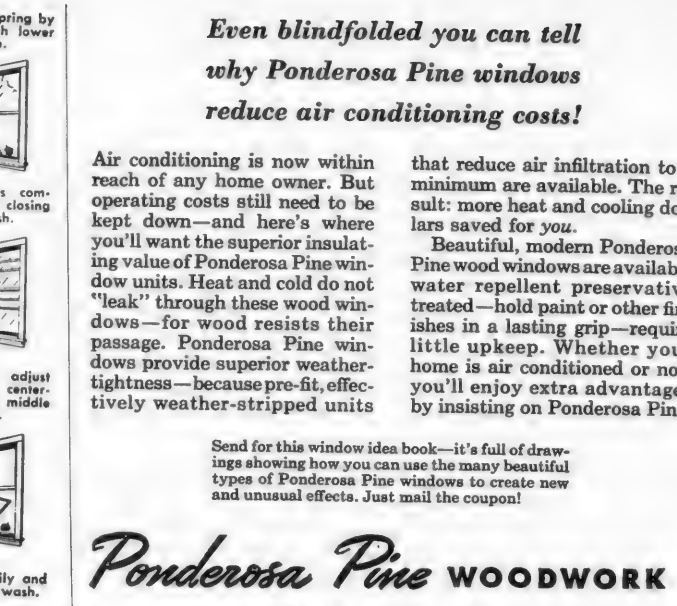
Let's see what wood's competitors are saying, by thumbing through a few pages of *House Beautiful's Building Manual*. A manufacturer of galvanized steel window units finished with baked enamel says: "To anyone who has had any experience in building, the shortcomings of conventional windows is painfully obvious. But finally someone

Table I.—PERFORMANCE CHARACTERISTICS OF LUMBER

1. Pleasing to the senses of sight and touch known as appearance, rating excellent.
2. Ability to withstand the action of external forces known as durability, rating excellent.
3. Ability to be easily handled, transported and applied known as handleability, rating good.
4. Ability to withstand the action of the natural elements and destructive agencies known as permanence and stability, rating fair.
5. Ability to be fabricated, finished or installed, modified, repaired and maintained known as workability, rating excellent.
6. Ability to provide comfort against heat, cold and noise, rating excellent.
7. Uniformity, rating good.

Aluminum Windows
Fleetlite is the revolutionary new window—the complete year-around unit combining interior and exterior double hung windows and screen in a four channel extruded aluminum frame — warmer in winter, cooler in summer — the greatest advance ever in window engineering.
The lasting lustrous beauty of extruded aluminum, the Koroseal mounted glass, the plastic screen, all sash so easily removed (for cleaning) from inside, contribute to new living standards. Gone is the annual task of removing, storing, cleaning, repainting and installing cumbersome storm windows and screens.
GONE FOREVER:
Removing Screens
Storing
Cleaning Storm Sash
Repainting Storm Sash
Installing
When you build — plan for the future, insist on Fleetlite
Welcome Spring by raising both lower sash.
Stop storms completely by closing all sash.
Block rain, adjust air flow by centering the two middle sash.
Remove easily and quickly to wash.

Ad 1. Competition


Even blindfolded you can tell why Ponderosa Pine windows reduce air conditioning costs!
Air conditioning is now within reach of any home owner. But operating costs still need to be kept down—and here's where you'll want the superior insulating value of Ponderosa Pine window units. Heat and cold do not "leak" through these wood windows—for wood resists their passage. Ponderosa Pine windows provide superior weathertightness—because pre-fit, effectively weather-stripped units that reduce air infiltration to a minimum are available. The result: more heat and cooling dollars saved for you.
Beautiful, modern Ponderosa Pine wood windows are available water repellent preservative treated—hold paint or other finishes in a lasting grip—require little upkeep. Whether your home is air conditioned or not, you'll enjoy extra advantages by insisting on Ponderosa Pine.
Send for this window idea book—it's full of drawings showing how you can use the many beautiful types of Ponderosa Pine windows to create new and unusual effects. Just mail the coupon!
Ponderosa Pine WOODWORK

Ad 2. Wood Industry

has done something about taking windows out of their horse and buggy stage and bringing them up-to-date."

A steel sectional garage door manufacturer describes his product thus: "Will not rot, warp or absorb moisture —can be painted with regular house paint."

A masonry house promotion association describes its products as: "resistant to fire and decay with continuing economy of low maintenance."

A shale tile manufacturer says about this product: "*With the authentic texture of the typical wood shake,* the product has no equal in permanence—no peer in beauty. An investment in low insurance and maintenance."

An aluminum window manufacturer says: "Can't swell, stick, warp, shrink or rattle."

Now the promoters of wood are not all taking it lying down. Let's look at a pair of advertisements featuring the same use.

Ad No. 1 shows the story one aluminum window maker puts out. Apparently he has done a praiseworthy design job and it is well to remember that design of the finished article is a consideration at least as important as the characteristics of the basic material, because design can materially enhance or detract from the total performance. The keynote of the ad is the perfect compliance with the requirements of use. Ad No. 2 tells the story of ponderosa windows, the keynote of which is the elimination of the old deficiencies.

How serious is this indictment of wood: lack of permanence, high cost of maintenance, lack of stability to moisture, the hazard of fire. Let's see what lumber's volume trend has been versus competition.

Let us look at one major use, exterior walls, in one principal market, construction. Construction accounted for 68 percent of lumber consumption in 1953, residential construction was 56 percent of total construction, so we are talking about 68 times 56 or 38 percent of total consumption. Of this, exterior walls may be perhaps one-sixth. In any event it's a lot of lumber. Exterior walls include framing, sheathing and siding.

20-Year Forecast for Wood Markets

Weyerhaeuser arranged with Stanford Research Institute some months ago to carry out a broad study of the economics of forest products, directed toward an understanding of the past and projection of the trends into the future.[2] Certain of the findings are pertinent to the question: What has happened to volume?

We are accustomed to looking at total lumber consumption figures, use per capita, total housing starts and so on, and then to wonder what it all means. I am going to dodge all those generalities and get down to the grass roots, namely, what has happened per residence, or as Stanford says, per dwelling unit.

Fig. 1 shows the effect of architectural changes and competition upon lumber consumption per dwelling unit for the last 33 years. In 1920 competition took 10,700 board feet out of 29,600 potential or 36 percent. Based on 1920 potential, by 1953, architectural changes took 33 percent, competition 31 percent leaving for lumber 36 percent. That's easy to remember, 1/3 lost by design, 1/3 to competition, 1/3 left. Now how has competition performed relative to the market available, 36 percent in 1920, 47 percent in 1953, up 1/3.

What are these architectural changes? Fig. 2 is Stanford's picturization. If you want to check this, you will find in *House Beautiful's Building Manual* 1953–54, 35 house plans. Of these, one is two stories, three are 1½ stories, 31 are 1 story.

Table II tabulates loss of lumber volume in exterior walls per dwelling unit caused by design and by competition, based on 1920 total potential and also on potential for each year shown.

The pattern of decrease is much the same as for the whole dwelling unit except for the last column on the right shown more clearly in Fig. 3. We were doing fairly well 1920 to 1940, then something serious happened, which has recently been accelerated.

Causes of Siding Failures

Now I would like to be more specific and talk about lumber siding as a major element in exterior walls. Lumber siding is painted for appearance. The paint film soon blisters, cracks and falls off. The home owner repaints on the best local advice he can get and the same thing happens again. The lumberman says it's the paint, the paint man says it's the lumber and the expert says it's condensation. In the meantime every friend and relative of the home owner says no lumber siding for me and the next houses are finished with something other than lumber siding.

Lumber siding is a very important part of our lumber line so we've been doing a little self-education with the help of the U. S. Forest Products Laboratory. Fig. 4 shows the backs of two

[2] See Journal of FPRS, October, 1954, or write FPRS Executive Office, Madison, Wis.

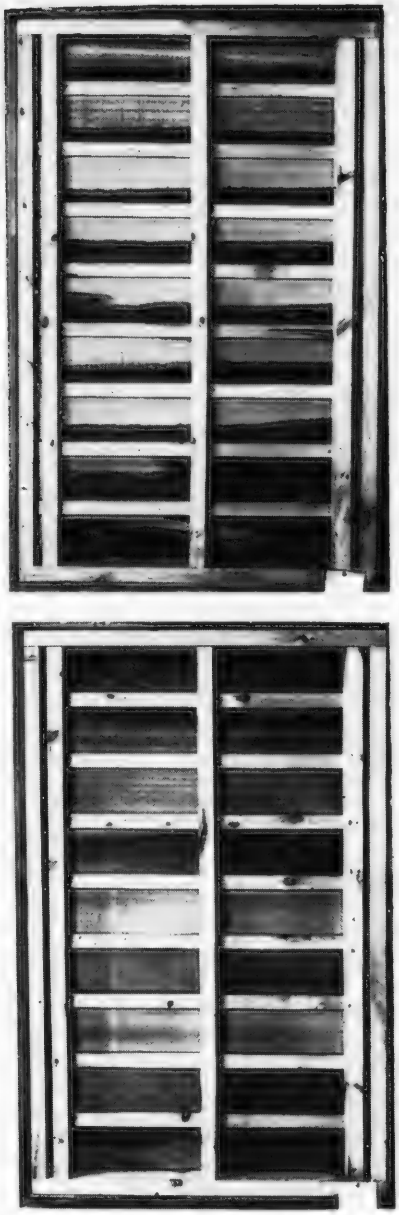


Figure 4.—Untreated and treated VG cedar siding after 4-hour exposure to water spray.

test panels of unpainted siding, the left one as is, the right one rendered water repellent, both after 4 hours exposure on the faces to a simulated gentle rain. The back of the untreated panel is saturated with water; that of the treated panel, substantially dry. It does not take much imagination to visualize what must happen as the untreated panel moisture travels to the interface behind a poorly bonded paint film of too little porosity. We have always blamed blisters on faulty construction (leaky roofs) and cold weather condensation. To these we now add rain. We haven't time to talk about the twenty years of collecting evidence by the Forest Products Laboratory, but perhaps Fig. 5 will shed some light.

Table II.—CONSUMPTION OF LUMBER PER DWELLING UNIT EXTERIOR WALLS

Year	Total Possible B.F.	Actual B.F. Lumber	% of 1920 Lost by Design	% of 1920 Lost to Competition	% of Possible Each Year Lost to Competition
1920	5660	2520	--	55	55
1930	4710	2370	17	41	50
1940	4001	2100	29	34	47
1950	3550	1748	37	32	51
1953	3630	1598	36	31	56

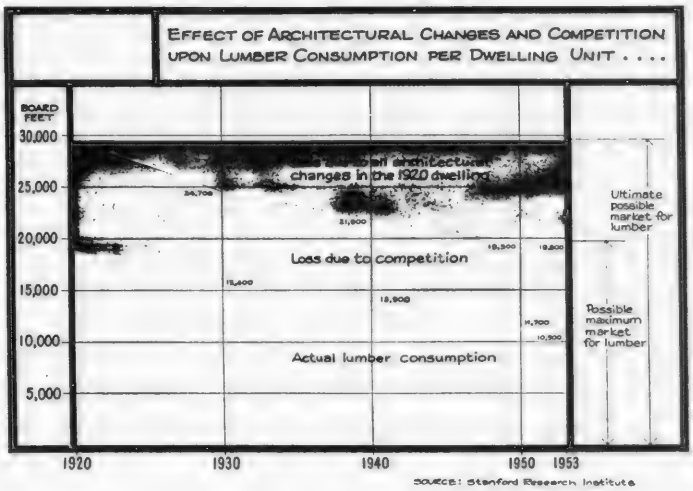
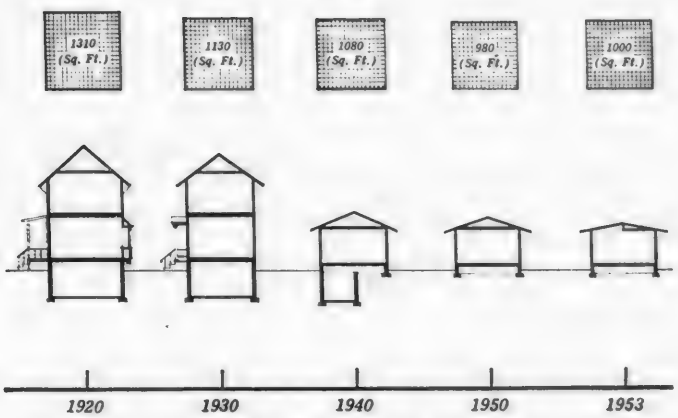


Figure 1



THE CHANGING CHARACTERISTICS OF THE DWELLING UNIT
(The United States Composite Average)

Figure 2.

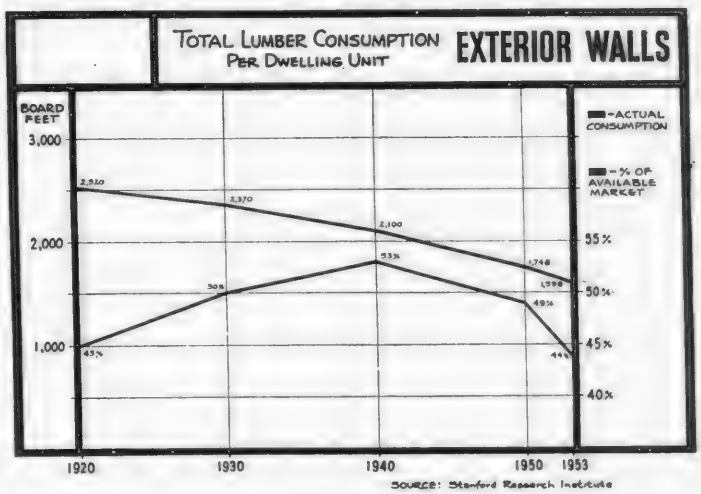


Figure 3

Figure 5.—Exposed in blister box followed by one year's outdoor exposure.

Here we have a pair of panels, the left one water repellent, the right one untreated, both finished with the same four compositions of paint. The wood is flat grain hemlock, particularly useful for test purposes. The panels were first subjected in the laboratory to severe conditions to induce cold weather condensation, then given outdoor exposure for one year. We find two paints have failed badly, one moderately, one has not failed.

From this and many observations of other panels we conclude that for cold weather condensation, the control of paint quality is of at least as great importance as the control of wood characteristics.

Performance Above Price

To summarize for a moment and ignoring the factor of outmoded designs wherever they occur, wood stands indicted for performance deficiencies and the evidence indicates the charges are serious. These are old problems. A few people have taken remedial action. Why not everyone?

Performance and price go together to make value. Eliminating deficiencies increases cost hence price. It has probably been decided in the past that the consumer would not pay any more for the better performance so let it go. Now competition teaches again that performance comes first price comes second.

Now I've spent more time on this first topic of markets, uses and competition than I should but it seems to me the responsibility for achieving the highest value of lumber for each consumer use comes first. It is the key to orders, to earnings and to profitable integrated utilization.

Earlier I mentioned the other merchandising factors of consumer preference and consumer service. I'll summarize two recent experiences. I attended a so-called Home Show in Seattle. Table III shows what I found —not a very reassuring picture.

Wood vs. Competition

Mr. John Reno, Utilization Director for the Pacific Lumber Company has given me permission to quote from recent correspondence relating to the new marketing committee of FPRS. He feels the following two reasons are largely responsible for the poor showing the wood industries are making in competition with alternate materials:

1. The policy of directing most of their promotion toward the dealer instead of the public in contrast with the aluminum producers who pound away at consumer preference to which, once established the dealer caters as the path of least resistance.
2. The unwillingness to indulge in promotional campaigns in which a spade is called a spade in revealing the weaknesses of competitive materials and the advantages of wood.

Without going farther, the responsibility for wood's future order file must include the critical examination of current merchandising techniques and if major changes are justified, let's get on with the job.

Reducing Manufacturing Costs

The second of our three major responsibilities relates to manufacturing cost, capital investment and earnings. In development work, one must think and talk economics even before a project is placed on the experimental program. So one learns to use the tools of the financial man to differentiate between sound and unsound.

In Table IV I have assumed a simplified operating statement, with corresponding investment, and three useful calculated ratios. The key to the economic status is of course six percent earnings on investment. We desire that this increase or at least not decrease for many good reasons. This is accomplished by decreasing cost or investment or both.

The two bottom ratios are helpful corollaries in plotting one's course by comparison with what others are doing. The ratios assumed are general averages for successful businesses. It is clear

Table III.—TALLY OF BOOTHS AT SEATTLE HOME SHOW, FEBRUARY 1954

Forest Products	Alternates
Hardboard (one)	Aluminum Sash (several)
Lumber Dealers (two)	Aluminum Screen and Screen Door (several
Packaged Wooden Door and Door Frame	Plastic Tile (many, 29c to 59c/sq. ft.)
Modular Wooden Kitchen Cabinets (one)	Enameled Steel Tile (two)
Garage Door (one)	Modular Metal Kitchen Cabinets (three)
Cedar Plank Wall Construction	Asbestos Cement Shingles (many)
	Concrete Block Wall Construction
	Heavy Vinyl Floor Tile
	Demonstration of Apprentice Masons
	Aluminum Garage Door (two)

Table IV.—RESPONSIBILITY FOR SOUND ECONOMICS

	Assumed Operating Statement, Investment, and Useful Ratios		Future Changes Required
1.	M $ Net Sales	10,000	Controlled directly by Product Value and Competition, indirectly by Net Earnings
2.	M $ Total Mfg. Cost Direct and Indirect including Depreciation at 5% of investment	8,000	Down—Through a program of action
3.	M $ Taxes at 50% of Earnings	1,000	
4.	M $ Net Earnings	1,000	Up—Resulting from (2) and (5)
5.	M $ Investment	10,000	Down—Through a program of action
6.	% Earnings on Investment	10	Up Key Ratio Resulting from (4) and
7.	% Earnings on Sales	10	Up Corollary Ratio Resulting from (4 and (1)
8.	% Investment on Sales	100	Down—Corollary Ratio—Resulting from and (1)

hat we may travel either the reduced ost avenue or the reduced investment oute in maintaining a sound earnings o investment ratio. This is to say, sim- ly that an expensive plant in relation o sales volume requires high earnings 1 relation to sales volume in order to e sound.

Which of these two routes have we een traveling? I doubt very many of is would maintain we have been build- ng inexpensive plants. Just looking out he window, a bleached pulp mill in- estment is about 200% of sales, ply- wood and lumber are at about the 100% level.

It seems to me we have been direct- ing our efforts more toward cost reduc- ion and particularly toward integrated ise of the log, thus spreading the cost of the raw material over more products. Although every mill location is to a certain extent unique, Table V gives a material balance for a hypothetical saw- mill based on percentage by actual solid volume of the incoming rough logs.

You will note that the logs used are described as essentially sound. As inte- grated use of residuals is practiced, the log quality may decline to include lower grade saw logs, wood logs and even cull logs where the forest is over- mature. Thus the percentage of resi- duals rapidly increases.

Table V.—SAWMILL MATERIALS BALANCE BASED ON PERCENTAGE BY VOLUME (SOLID) OF ENTERING LOGS

Assumptions:
Only sound good quality logs sawed
Average log contains 150 total cu. ft. per MLS (24" diam. by 32' long)
95% of output is dried and surfaced
No integration of residuals use

Bark		10
Green Sawdust	12	
Green Chippable (Slabs, edgings, trim)	16	
Green Residuals		28
Dry Shavings	10	
Dry Trims	6	
Dry Residuals		16
Drying Shrinkage		4
Lumber		42
		100

We have been concerned principally with use integration of chippable green slabs, edgings and trims or a minimum of 16 percent of the incoming volume under conditions assumed in the Table. We have largely ahead of us, use of green sawdust, dry residuals and bark amounting to some 38 percent of the incoming volume.

In the pulp and paper business there is great justification for cheaper plants of smaller size operating continuously with high weight yield of pulp product, the process being designed to accom- plish complete utilization of the raw material but not as fuel. That portion dealing with operating continuously with high weight yield is an accom- plished fact. I was recently privileged o observe the continuous experim ntal roduction of pulp in a matter of min- utes, using thin vertical grain shavings. We are closer to these goals than many realize.

Without laboring the point further our future economic responsibilities are clear: We will build cheaper plants lowering investment. We will employ simpler processes lowering costs and investment. We will increase product yields, by volume or by weight as gov- erned by what we sell, again lowering costs. We will utilize all the residuals again lowering costs.

Greater Utilization

As the third and last topic I can't resist the temptation to discuss a bit further this matter of utilizing, through integrated manufacture, all the wood we grow.

Limiting the discussion to sound mill residuals and referring again to Table V, our future raw material is in three forms, namely dry shavings including dry sawdust, green sawdust, and bark, the quantities of the three being sub- stantially equal. What are we going to do with them?

Let's dispose of bark. It is the first residual we encounter because it ha. been proven profitable to bark saw logs, both for lumber and for the values in bark-free residuals. Ten years ago very few people were even thinking about bark utilization. Today there are com- mercial plants and more pilot plants. Interest is widespread. The various barks are an amazing source of organic chemicals easily separated from the lig- nocellulose of the hard tissue, but dif- ficult to isolate in useful purity. They will furnish the basis for a sizeable chemical industry quite unlike one based on wood. It is one of our future responsibilities to see that this industry materializes.

We need not spend time talking about chippable residuals, except to ob- serve that the small sawmill producing chips must have an adequate market, which brings the spotlight again upon the necessity for cheaper smaller utiliza- tion plants already mentioned as a fu- ture responsibility.

We have next to deal with shavings and sawdust as pieces of wood, or as aggregates of fiber, or as blocks of chemical compounds. Utilization of shavings bonded to board form is al- ready well on its way. This generic product will go far if we can tailor it to achieve an attractive performance at an economic price and I believe we can. Utilization of shavings and sawdust for fiber so far as I know is still ahead of us. Granted that the fibers have been cut and no doubt badly so in the case of the finer portion of sawdust, I think it is reasonable to expect that fiber from the coarser particles can find plenty of utility whether as whole wood fiber or variously delignified.

This brings us finally to a considera- tion of chemical utilization, the most logical means of dealing with the small particle use problem.

We are all well aware of the very small part wood plays at present as a commercial chemical raw material. I do not include the vast consumption for papermaking fiber, useful primarily be- cause of its physical attributes. I am cognizant of the substantial progress made in producing chemicals from waste sulfite liquor. I would not mini- mize these accomplishments but I doubt that they are motivated by any desire to make wood a commercial chemical raw material.

I do include as chemical the million tons of chemical cellulose produced annually. One and one-half million tons of pine stumps are extracted an- nually for naval stores on which the Hercules Company has built a complex chemical business of unique and useful derivatives. Pyrolysis of wood is all but extinct. Unsuccessful attempts to com- mercialize acid hydrolysis to yield mo- lasses go back 50 years. Wood molasses must compete with blackstrap in a world-wide free market. The Cubans recently sold this season's blackstrap at 8¢ per gal.

If we can agree on what is really wrong with this chemical utilization picture we may be able to put down some specific future responsibilities. For commercial success the technology must be practical and adequate, the economics sound and the timing right. None of the three have been fulfilled in the case of wood. Adequate tech- nology means a scientific understanding of the chemical composition of the raw material, of what happens in the process steps, of how to isolate groups of like useful chemical products, of the details of a materials balance. Sound econom- ics means converting all the raw mate- rial to marketable products. Timing in- volves the urge of necessity. No one is clamoring for the chemicals wood could produce.

I have two suggestions to make for the future. The first is to perfect our determination of the whole composition of wood based on the compounds actually present, minimizing empirical methods and ruling out expressions in- volving functional groups as such. The second is to stop using a steam hammer on a delicate and sensitive material as has been done for years in delignifica- tion, pyrolysis, hydrolysis and even ex- traction. If we can fractionate wood into like constituents little changed, we may then be able to devise secondary processing which will really put us in the chemical business.

Status of Research in Utilization of Small Hardwoods[1]

FRED C. SIMMONS

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There are many opportunities for increased marketing of small hardwoods—through research. Delivered price must be kept low; specifications rigid. Research is also needed in actual processing techniques. There is no quick or easy solution—answer lies in coordinated effort by all interested organizations.

PRESIDENT EISENHOWER, when he was commander of the NATO forces in Europe, used to describe the European political situation, as it applied to measures for common defense, as a "can of worms." No matter what phases he tried to isolate, to determine its effect on defense plans, he found it almost inextricably tangled with a dozen other things.

That's exactly what I have found in trying to prepare this discussion of the status of research in utilization of small hardwoods. Practically every problem that I have considered is so tangled with other aspects of forest management and utilization that it is practically impossible to isolate it.

Utilization of small hardwoods is only one phase of the general problem of hardwood utilization. Every part of the United States east of the great plains is confronted with a surplus of hardwood growth over drain. In general, this is a surplus of everything but the high-grade portions of good trees in heavy and accessible stands. It includes not only small trees but also low-grade trees of larger size, low-grade portions of the high-grade trees, including tops, and even high-grade trees that are too scattered or inaccessible for economical logging.

We estimated in 1945 that whe had an annually accumulating surplus in New York and New England of more than 6 million cords of hardwoods. Growth was estimated at 10 million cords, and drain, for all purposes, at 4 million. This annual surplus was twice the total consumption of all the pulp mills in the area. In other words, if all the pulp mills had converted overnight to using only hardwoods, and all their consumption had been taken from domestic growing stock, there would still have been an annually accumulating surplus of 3 million cords of hardwoods.

[1] A contributed paper originally presented at the Spring, 1954 meeting of the New York Section, Society of American Foresters.

Now, because of loss of some markets, notably for fuelwood, and because growth is cumulative, the surplus is undoubtedly larger. In fact, a study of best available data will show that hardwood is now accumulating on the commercial forest lands in New York State alone at the rate of some 3½ million cords per year. In addition to this, about 350 thousands cords of hardwood tops from sawlog and veneer log operations are available annually, and about 200 thousand cords of coarse hardwood mill residues, including slabs and edgings, veneer cores, and like material are developing at New York mills each year.

This topwood, and more particularly these mill residues, must be taken into account in any program of developing market outlets for small hardwood trees. Right now hardwood slabs have almost completely replaced round wood as the raw material for the Northeastern charcoal industry. A cord of slabs contains about the same volume of wood and bark as a cord of round wood, although a larger percentage is bark. Bark does not make as good charcoal as wood, but coal from bark seems to be perfectly salable in the picnic market, which is the mainstay of Northeastern producers.

The same thing is true of fuelwood. In 1952 New Yorkers used only 148 thousand cords of hardwood fuelwood from growing stock. But in the same year they used 213 thousand cords of hardwood mill residues for fuel (including both fine and coarse material). Slabwood, of course, can be obtained delivered in many localities form $5 to $7 a cord (and bark usually produces more B.t.u.'s than solid wood). Round wood, on the same basis, costs $15 to $18 and even more a cord, largely reflecting the cost of woods operation.

These price differentials are of great interest to the pulpmills. Almost every pulpmill I know of is investigating the possibilities of collecting and processing slabs and other mill residues

New England "snapdragon" or short log bolter gives greater recovery and higher quality sawed material from small hardwoods than standard long log mill.

as a potentially cheaper source of pulp chips. Unused coarse hardwood mill residues in New York State in 1952 amounted to the equivalent of 94 thousand cords. In the same year New York State produced only 68 thousand cords of hardwood pulpwood from its own stands.

So much for the general background. Table 1 gives the best current estimate I have been able to compile of hardwood growing stock in small trees in New York State, and present drain on this growing stock. This indicates that our best market for small stuff is still for fuelwood, amounting to about half of the total. Hardwood pulpwood amounts to only about 23 percent of the total current market in New York for small hardwood. Many of you will be surprised to learn that we are now using almost as much volume from small hardwoods in our sawmills as we are in our pulpmills. (By "small trees" we mean what the Forest Survey calls "poletimber"—trees 5 to 11 inches d.b.h.)

For management specialists interested in better information as to where this volume is located, I have included table 2. As you will see, about 46 percent of these small hardwoods is intermingled in sawtimber stands, and 37 percent is in good poletimber stands, averaging 9.6 cords of hardwood per acre. In addition, we estimate that New York has about 7,500 thousand cords of small hardwoods in rotten and sound cull trees scattered through all types of stands.

All in all, this is a tremendous and increasing resource. Certainly more than ½ percent of it should be cut in the interest of good forest management and good economics. How much more I won't venture to estimate.

What is being done by our research institutions and industries to make a greater proportion of this material marketable? Let us consider some of the past accomplishments, current programs, and unfilled needs.

Logging

First of all, if small hardwoods are to be used in considerable quantities by industry, there must be assurance that suitable material can be secured at a reasonable cost, and at a sustained rate. This is a big order. At the present time we must admit that it cannot be filled, not by a wide margin.

In the first place, what constitutes suitable material for the various uses to which small hardwoods can be put? During the past few years the Northeastern Forest Experiment Station has been collecting specifications used by firms in the Northeast in buying their raw material. They are widely divergent, even among firms making essentially the same product, by the same processes. Typically, also, they are so loosely drawn that they leave a wide degree of latitude for individual buyers and inspectors, and we find that application varies between different buyers for the same firm, and with the same buyer at different times.

The result is that some firms are getting material too poor for their particular process and use, thus depressing the price they will pay for all the material they buy. Other firms are getting better material than they need.

The U. S. Forest Products Laboratory at Madison, Wisconsin, is preparing an "Overall Work Plan for Development of Log Grades for Hardwoods." This is intended to serve as a guide for all agencies engaged in investigating various aspects of this subject, including grades for boltwood. It includes suggestions for detailed studies of defect characteristics to determine their importance, and for developing and testing improved grading specifications. For some time the Northeastern Forest Experment Station has been planning a study of hardwood boltwood operations in cooperation with Laboratory technicians. This would result in a set of grade specifications for this class of material. Some preliminary work has been done. Ken Compton has also done some work at Syracuse. We hope that other workers and institutions will become interested.

The Division of Forest Economics of the Northeastern Station is also trying to get the two technical committees of the American Pulpwood Association in our territory to agree on a standard set of specifications for hardwood pulpwood, which can be used on the Forest Survey, and by buyers and sellers.

Work is also needed, and is being discussed, on standardizing specifications for round mine timbers, charcoal and fuelwood, and a variety of other products.

When sound specifications have been devised and adopted, the buyer will know better what he is getting, in terms of its velue to his business; and the logger will be able to cut and sort his wood with greater confidence that it will be acceptable, without deduction in price or quantity, by the industries for which it is intended.

As you all know, great changes have been taking place in Northeastern logging methods in recent years. Mechanized equipment is fast taking over practically every phase of the job, from opening up the stands to delivery of the products. Younger men, commuting from their homes, are doing more and more of the work. Operations are being conducted year 'round, with smaller crews, instead of seasonally. All of these things have not succeeded in halting—or even slowing down—the steady upward trend in the cost of operating small hardwoods.

As a result, hardwoods from the woods have practically priced themselves out of several markets, notably those for charcoal wood and fuelwood. In the 30's charcoal plants in the Catskills were getting round wood for $4 a cord. Now they cannot get it for less than $12 or $15 a cord. Consequently, most charcoal and fuelwood is now coming from mill residues. The same thing may easily take place, in the very near future, in the case of hardwood pulpwood.

The best hope, as I see it, of our being able to retain and expand the market for small hardwoods in bulk and low price markets, is to practice multi-product or integrated logging and utilization to the very limit possible. In any cut of small northeastern hardwoods, from almost any stand, there are these high quality materials. Sometimes they may be clear sapwood side cuts from hard maple or yellow birch bolts, or they may be entire small veneer logs or turning bolts from these and other species. If these are recognized, and segregated and sold for what they are worth, often ten times as much as the remainder of the cut, there is a better possibility of delivering pulpwood, charcoal wood, fuelwood, or other lower grade hardwood products at a price that the user can afford to pay. This is now being done in numerous cases. Much additional research

Table 1.—USE OF SMALL HARDWOODS (5 TO 11 INCHES D.B.H.) IN NEW YORK STATE, 1953

Species	Present stand M cords	Cut for— Lumber M cords	Pulp M cords	Charcoal and fuel M cords	Posts M cords	Excelsior and other M cords	Total cut M cords	Percent
Oaks	9,000	1	2	20	5	-	28	.3
Yellow birch Sugar maple Beech	6,800 11,700 7,300	34	20	54	13	-	121	.5
Hickory, ash, elm	8,000	3	--	23	4	-	30	.4
White birch	3,500	6	4	15	2	-	27	.8
Red maple Basswood, black cherry	9,900 4,100	1	2	34	7	-	44	.3
Aspen	4,700	--	40	2	2	5	49	1.0
Total	65,000	45	68	148	33	5	299	.46

Source: Preliminary data from forest survey, compiled by Northeastern Forest Experiment Station, U. S. Forest Service.

Table 2.—LOCATION OF VOLUME IN SMALL HARDWOOD TREES (5 TO 11 INCHES D.B.H.) IN NEW YORK, 1953

Kind of stand	Area M acres	Volume M cords	Cords per acre
Sawlog stands	4,559	29,779	6.5
Good poletimber stands	2,524	24,226	9.6
Poor poletimber stands	1,752	7,236	4.1
Other stands	3,168	3,914	1.2
Total in growing stock	-----	65,155	...
In sound cull trees	-----	6,021	...
In rotten cull trees	-----	1,561	...
Total	-----	72,737	...

Source: Preliminary data from forest survey, compiled by Northeastern Forest Experiment Station, U. S. Forest Service.

needs to be done to develop this basic idea to commercial practicality in its various applications.

What is needed are some drastically new developments in wood procurement methods and equipment. During the past year we made, under the auspices of the Forestry Committee of the New England Council, a survey of research being conducted in logging and wood transportation in and applicable to New England. Twenty-eight different research projects, practically all of which could be applied to the logging of small hardwoods, were listed. Only one of them was listed by any of the seven colleges of forestry in New York and New England. That was the chemical-peeling project at Syracuse. Only one agricultural experiment station was doing any work in the field. That was Ed. Foss' project on developing tools and devices for the woodlot logger at Cornell. The Northeastern Station listed four projects, two in the Upper Darby Office and two at the Research Centers; and the Bangor and Aroostock Railroad had one. The remainder of the work was being done by the loggers themselves and the equipment manufacturers. Two New England pulpmills indicated that they were experimenting with new types of crew organization and methods. International Paper in New York was experimenting with gravity skidding by wire. New mechanical debarkers and mobile chippers were being developed by several concerns.

This survey showed that many of our people, and particularly those in the pulpwood industry, are concerned about the problems of mounting costs. Much more research needs to be done. The present program is far from adequate to meet the need.

Pulp Manufacture

The use of Northeastern hardwoods for pulp is not new. Most of the hardwood, until recently, was converted by the soda process. Aspen and other soft hardwoods were the favored species. The resulting pulp was low in strength, low in yield, and of limited utility.

But recent developments have enormously broadened the possibilities of using hardwood for pulp. The semi-chemical process was developed at the Forest Products Laboratory 25 years ago to help utilize blight-killed chestnut. (The product was a low-grade board.) Since then the process has been improved so that practically all hardwood can be pulped, and the resulting pulp can be used, with bleaching, for such things as glassine, and to replace sulfite pulp in book and writing papers. Yields of bleached pulp as high as 65 percent are obtained.

The sulfate process has also been found to be adaptable for hardwoods, particularly the denser ones like beech, birch, maple, and oak. High-grade pulps are obtained. One Northeastern company which has shifted a large portion of its capacity to sulfate has a book of testimonials from its customers, many of whom claim that the new bleached hardwood sulfate pulp is as usable in their product as the high-grade spruce sulfite they formerly purchased. Most soda mills are adding sulfur to their cooks, primarily to enable them to use more of the higher-yield dense hardwoods and obtain a more versatile product.

The chemi-groundwood process, developed at Syracuse, has considerable promise of opening another market to hardwoods for pulping. The first commercial installation has now been made in Maine.

Further research needs to be done on the details of all the processes to increase the utility of the product and reduce costs. Another new process—cold alkali—is being investigated at the Forest Products Laboratory. Of increasing importance, however, is work that will develop means for reducing pollution by pulpmills, both of water and of the air. I know of several planned installations of pulpmills in downstate New York that never materialized, primarily because of these pollution problems. Anti-pollution regulations are particularly strict on the Delaware. Considerable research is being done on these problems, and success seems to be imminent.

New York is falling far behind its sister states in the swing to hardwood for pulp. Only 11 percent of New York's 1952 pulpwood cut was hardwood, while the average in all the Northeastern States was 30 percent.

Sawbolt Conversion

Use of small hardwoods by sawmills is here, and in my opinion it will increase rapidly. The short-log bolter mill makes conversion economically attractive. For years bolters have been used to produce squares and bars for the wood-turning industry in New England, particularly in Maine. Originally white birch was the only species processed, but in recent years the turners have had to shift to other hardwoods, particularly maple and beech. Other users of hardwoods in small sizes have discovered the utility of the bolter. Furniture manufacturers particularly have siezed upon it as the means for getting continuing supplies of high-grade hardwoods in the sizes they need.

I recently made a study of a short-log bolter operation in Vermont. This machine was producing about 7,000 board feet a day of 4/4 and 6/4 dimension from maple and beech bolts averaging 12½ inches in diameter. It was getting 1,000 board feet of product from 140 cubic feet of logs. Long-log mills, operating the same size and kind of material, were using 184 cubic feet of logs to get 1,000 board feet of product. The product of the bolter mill was straighter-grained, more accurately cut, and contained a higher percentage of the better grades, than that of the long-log mills.

Another bolter mill studied was in New Hampshire. It was cutting sticks averaging 7½ inches in diameter, and was getting 1,000 board feet of product from 169 cubic feet of raw material. We have no long-log mills with which we can compare this installation, of course. Long-log mills studied required logs 15 inches in diameter to get this percentage of recovery.

We hope to have a lot more of this kind of data in the future as a result of planned work, both by our organization and by others such as the State University of New York, College of Forestry at Syracuse.

Studies are also needed, and are planned, on the reduction of difficulties being experienced in drying stock produced from small hardwoods. Considerable cupping, warping, and checking has been reported by some kiln operators unused to handling this type of material. Excessive shrinkage in drying is also complained about.

Further research should also be done on machining, gluing, and fabricating dimension stock from small hardwoods. Preliminary indications are that the difficulties being experienced are largely associated with rapidly grown trees. Those that have grown at a slow, even rate, comparable in rings per inch with the old growth, seem to present fewer difficulties in drying and manufacture.

Veneer

It may seem illogical to include veneer in a discussion on markets for small hardwoods, but it is not so far-fetched as you might think. Recently considerable birch plywood from Finland has been available in the Philadelphia and New York City markets. On some of this you can see, from repetition of the grain pattern, that face veneer was cut from 7- and even 6-inch diameter bolts.

Some of the small high-speed veneer lathes on which this is being cut are manufactured in Lockport, New York. One veneer mill in Maine has installed one of these Scandinavian-type lathes primarily to cut its cores down after the big lathe is through with them. Many of these cores are cut down to a diameter of 2½ inches. There is also considerable interest among our industries in European-type veneer slicers adapt-

ted to use with small hardwoods. One, developed in Germany, uses no dogs, depending on hydraulic pressure to hold the bolt against the action of the knife and to feed it forward between each cut.

Consequently, veneering offers considerable promise as a method of converting small hardwood bolts of high quality. Research institutions should be investigating these possibilities.

Fuelwood

The principal need, to keep hardwood fuelwood in the picture, as has already been discussed, is to reduce its delivered price. At present round wood is definitely in the luxury class as a fuel, costing approximately twice as much as coal or oil per thousand B.t.u.'s delivered. This is more and more restricting its use to fireplaces.

Most of our traditional wood-burning devices are notoriously inefficient. Wood burns with a long flame, and it requires a secondary source of air for complete combustion. Much work has been done on the development of better wood-burning stoves, both in Europe and this country. Considerable success has been attained. More could well be done to make the special wood burners now on the market sturdier, more foolproof, and still more efficient.

Closely akin to the use of wood for fuel is its carbonization into charcoal. In recent years the demand for picnic charcoal has been growing by leaps and bounds. At the same time, because they could not compete with synthetic sources for their byproducts—methanol and acetic acid—the big charcoal retort plants have been dropping off lime flies at the first cold snap. The increasing demand for charcoal has been met, in large part, by kiln installations making this material as their sole product. The design and operation of charcoal kilns, particularly those of intermediate size, needs to be improved. Work on this is planned at the Forest Products Laboratory, in cooperation with several other interested agencies.

For charcoal, too, the big need is to develop ways and means of delivering wood from forest stands to the plants at a more reasonable cost.

Posts and Poles

The use of native wood for posts and poles has been declining. There are a number of reasons for this. Among them are the inroads of substitutes like concrete and steel, and even preservatively treated wooden posts from other regions. Cost undoubtedly enters the picture, particularly the current lack of cheap labor on the farms to continually replace decayed posts.

Nevertheless, there is a big market to be cultivated here, and considerable research is being done to help develop it. For years research and extension agencies have been attempting to promote more adequate home preservative treatment of native timbers. Now the emphasis seems to be changing to the encouragement of small local commercial treating plants. New treatments are being developed. Of particular interest and promise is the double-at the Forest Products Laboratory. This diffusion treatment recently perfected consists merely of a steeping of posts in a water solution, first of one chemical, then of another. The two chemicals react within the wood to form an insoluble compound.

Other treatments are also being tested and perfected in an attempt to retain and increase the farm post market, and also to develop or enlarge industrial markets for native species—such as highway guard posts, mine timbers, and utility poles.

Other Uses

There are, of course, many other uses to which the products of small hardwoods can be adapted. In most cases the primary problem is to get them to the point of consumption, in the proper condition, and at a reasonable cost.

One potentially tremendous use is for agriculture. It was the subject of a recent Northeastern Wood Utilization Council conference at Syracuse. With the swing to tractors on our farms, feed grains are not being raised in their former quantities, and farmers are actively searching for a substitute for straw for livestock bedding. Wood fragments have apparently been the best answer. At present about 50 percent of the fine waste from New York wood-using industries is being picked up by the farmers. In addition, several thousand cords of slabs and edgings are being hogged for this use. Most of the used animal bedding is spread on cultivated fields and pastures as a soil improver.

There has been considerable promotion, in recent years, of the idea of using raw chips on the land, either as a mulch, or incorporated directly into the soil. Results of tests of these practices have been contradictory. Recently, I met in New York with a group of soils specialists, representing the agricultural experiment stations of the Northeast, to discuss additional research to determine where, and under what conditions, wood fragments should be used on the land. Three Northeastern institutions already have fundamental studies under way on this problem, and undoubtedly other studies will be initiated. A comprehensive fundamental study on the effect of wood fragments on the soil has also just been started at the U. S. National Agricultural Research Center, Beltsville, Maryland.

Wood in raw form is also useful in metallurgical processes. The electrometallurgical processors around Niagara Falls are using considerable quantities of raw hardwood chips every year, in place of charcoal, in their furnaces. The supply is coming from slabs and edgings at the sawmills, once again because this is the cheapest source. Brass foundries in New Jersey and Maryland use considerable quantities of green hardwood "furnace poles" every year to clean up their melts. Both of these markets pay about $6 a ton green weight, for the wood they use.

Finally, we are continually being asked about the possibilities of the use of wood in new chemical processes, as forecast in Egon Glessinger's writings. It is unquestionably true that wood has the potentiality of making many chemical compounds such as those currently made from coal, oil, and other materials, including blackstrap molasses. The Forest Products Laboratory is continually working on processes to accomplish this. Some of this work is currently being done on a secret basis for the U. S. military forces.

Commercial application of these processes, however, must apparently await a decided change in our price structure. According to Dr. Alfred Stamm of the Laboratory, wood would have to be available at a chemical plant for no more than $3 a ton, dry weight, to equal current costs of competitive raw materials such as coal and oil.

Conclusion

There are a lot of opportunities for increasing the marketability of our native small hardwoods through research and application of research results. It is particularly important, for many of these applications, that the delivered price be kept low. For others with more restrictive requirements, it is important that specifications of the material to be delivered be known, and strictly followed. Much research is still needed to accomplish both of these ends.

Research is also needed on actual processing techniques for many products to reduce costs, increase efficiency, and improve utility.

All in all, utilization of small hardwoods presents a tremendous set of problems. The quantities available are so large, and the competition with other materials for possible markets so keen, that no quick and easy answers can be expected. The best that can be hoped for is that by continuous and well-coordinated work on various aspects of the problem by all agencies, both public and private, on a national, state, and local basis, some headway can be made.

Water Repellents Reduce Rain-Caused Paint Blistering on Wood Siding[1]

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Water is a common cause of paint blistering, and cold weather condensation is recognized as one source of such moisture. Water running down the face of siding may work through some of the vertical joints and through the lap of the bevel siding by capillarity. Methods of protecting siding from this source of moisture are suggested.

RAINWATER IS AN IMPORTANT though not generally recognized, cause of paint difficulties in wood-sided houses. It gains entry back of the siding chiefly by capillary action, working through the lap joint between courses of bevel siding. High winds are a minor cause. Laboratory tests have shown that entry of rainwater through house siding can be minimized or eliminated by dressing the back of standard-pattern siding so that a tight joint, which can be more or less sealed with paint, is formed between the courses; modifying the standard pattern by dressing the back side and adding a horizontal groove; treating conventional or modified siding with water repellent before it is nailed to the house; and applying a water repellent to the siding of a completed house before the house is repainted.

Introduction

Wood siding is the most popular exterior wall covering used on homes, and has been for centuries. Such siding is still in excellent condition on many colonial homes that are more than 300 years old and still in use.

Most wood-sided houses are painted, not only for decoration but also to protect the wood from weathering and from moisture changes that might cause warping. Unfortunately, many of our modern paints are more sensitive to moisture than those used some years ago, and, if too much water gets into the siding, the paints may blister and peel.

There are two main sources of this moisture: (1) water that accumulates by cold-weather condensation; and (2) rain water that is driven by the wind or works up in back of the siding by capillary action.

The cause of cold-weather condensation is well known and need not be discussed here, as methods of protection have been described in many publications, such as those listed at the end of this article.

[1] A contributed paper. Investigations were made in cooperation with the Weyerhaeuser Timber Company.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Rain water, however, is not generally recognized as a source of paint-blistering moisture, even though it may be as important a source as condensation. Some rain has always gotten behind siding, even in old houses that were protected with good overhang and narrow-pattern siding, but the paint on these old houses was much less sensitive to moisture than are our modern paints, and there was little or no trouble with paint blistering (fig. 1).

Figure 1.—Although water got in back of the siding of this 61-year old house, as shown by the paper and wood sheathing, the paint was still in good condition when the house was torn down.

Many of our modern houses are designed with no overhang at the gables and very little at the eaves, so that the siding is given little protection from rain. This lack of protection plus the moisture sensitivity of modern paints often results in paint failure (figs. 2 and 3).

An exploratory study was started at the Laboratory to find ways and means of improving the performance of beveled wood siding under service conditions and, particularly, to reduce or eliminate moisture entrance from the outside. The first objective was to determine how water got back of siding, the second to determine the effectiveness of modified siding patterns and treatments in preventing or reducing water ingress (fig. 4).

Methods of Test

Test Panels: Panels of 8- by 7/16-inch standard-pattern (fig. 5, *A, B*) bevel siding were made with 2- by 4-inch studs and frames and nominal 1- by 2-inch sheathing strips. They were assembled so that the back of the siding could be observed. When the panels were examined from the back in a dark room with a bright light on the face of the siding, a thin opening could be seen at each siding lap, where the band-sawed edges, which were slightly rough, made contact only at the high points.

The panels were painted and again examined. The paint had closed the opening between the boards at the lap. The panels were then placed in a dry kiln and exposed first to a high humidity and then to a low humidity to swell and shrink the siding at the lap and break the paint film at that point. This simulated the condition that occurs in service. Again light could be seen through many of the laps, but the paint had apparently closed some openings and partly sealed others.

The panels were then exposed to a spray so that water ran over the face of the panel from top to bottom. During exposure the back of the panel was examined regularly for appearance of water. With standard-pattern material, wet spots appeared irregularly on the back of the siding at the top of the lap and slowly crept upwards. In some cases, the spots covered one-half or more of the exposed area in 4 hours. The water had worked up through the laps and out onto the exposed surface by capillarity. In some cases, water flowed down from under the sheathing strips, and examination showed that this occurred when the nail had split the thin edge of the board under the lap. The split was actually concealed by the overlapping board. Water working upwards under the lap passed through the split and ran down the back face of the board, wetting the board excessively. This form of wetting may account for large local paint failures on a side wall where other areas have smaller, scattered paint failures.

Width of Lap: To determine the importance of the width of the lap panels were made with a ½-, ⅞- or 1¼-inch overlap. Nails were placed a scant ½ inch above the butt edge. No distinguishable difference in wetting was noted between boards having 1¼- and ⅞-inch lap. The wetting was much more general, how-

Figure 2.—The gable end of this house has little roof overhang, and the side wall is not protected from rain. The wide overhanging eave on the front gave good protection to the siding below, and the paint though spotted with dirt, is in good condition.

Figure 3.—The limited overhang of the gable end of this Florida house did not prevent frequent wetting from rains that damaged the siding and paint. The siding and paint on nearby houses with wide-overhang roofs were in good condition.

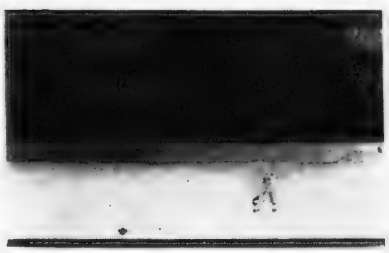

Figure 4.—Water found on sheathing paper when siding was removed in late September. The back of the siding was wet. The water had worked under the laps by capillary action.

ever, with the ½-inch lap because the nails split the thin edge. The wetting due to capillary movement of water was probably about the same regardless of width of lap. To prevent nail splitting at the thin edge, the lap should apparently be at least ⅞ inch.

Modified Siding Patterns: Several modified patterns (fig. 5, *C, D, E*) were tested to determine the effect of drip cuts, grooves, and back dressing on capillarity. A drip cut at the butt of ½-inch siding was ineffective. Water jumped the drip cut and followed the same wetting pattern as in the standard siding. Back dressing at the butt to provide a smooth surface in the same plane as the face of the siding was effective in reducing capillarity and in making a tighter joint at the lap so that the paint offered some mechanical resistance to moisture entrance. A horizontal groove on the back in the area covered at the lap also reduced capillary flow. The best results were obtained with a combination of back dressing and the horizontal groove.

Back painting at the lap edge, using two coats of paint, reduced wetting on the back to about the same degree as the back dressing. Presumably, such back painting would offer protection during the life of the paint. It is not believed that back painting with a single prime coat would offer much protection.

Effect of Wind: To obtain information on the effect of wind, the panels were placed in a five-sided revolving frame and exposed to a fan directing air against one face of the frame as it revolved (fig. 6). The air velocity at the face of the panel was the equivalent of a 40-mile wind. Water was sprayed on the panel in front of the fan. With all panels exposed to wind pressure, the water ingress was only slightly greater than in the tests where no wind was used. Under service conditions where the siding would not be so tightly and uniformly applied as it was in the panels, the wind effect could be expected to be more pronounced.

Treated Siding: Another series of panels was made with standard and modified patterns of siding that had been dipped for 3 minutes in a water-repellent preservative. These panels were painted, exposed in the dry kiln to cause swelling and shrinking, and then wetted in the same manner as the untreated siding (fig. 7). Regardless of pattern, the treated material was consistently free from wetting on the back. There was no evidence of capillary action nor of the wetting caused by splits on the thin edge. When the panels were exposed to wind in the revolving frame, there was evidence of some minor, relatively unimportant wetting on some of the panels.

Panels were also made up of treated and untreated standard-pattern stock and tested without being painted. Here again there was no evidence of capillary wetting on the back of the treated material, but there was general wetting on the untreated material (figs. 8 and 9). Perhaps this means that, where treated siding is used, priming need not follow immediately after the siding is applied but could be deferred to a time more convenient to the builder.

Results of Tests

The results of the tests on untreated siding show that a very material reduction in water ingress may be obtained by the use of back dressing and grooving as described. The exposure conditions in the test were severe, and under service conditions the protection pro-

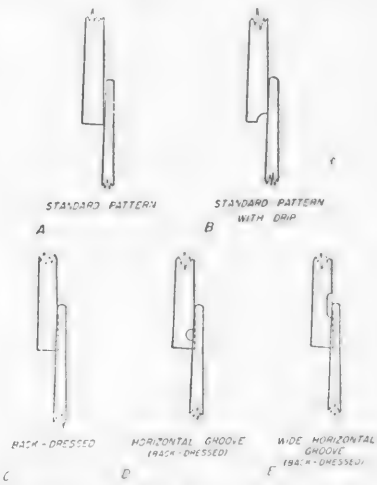

Figure 5.—Siding patterns tested in the exploratory studies.

Figure 6.—Turntable and fan used in exposing panels to wind test.

Figure 7.—The panel on the left was made up of treated material, that on the right of untreated material. Note the difference in the water pattern.

vided would mean better paint performance than that found with standard-pattern, untreated siding.

The results of the tests with water-repellent preservative were particularly impressive and indicate that, if it is used, the pattern would be unimportant. In spite of the good results on treated, standard-pattern bevel siding, it would seem desirable to back-dress to obtain a better and tighter joint at the lap to reduce openings through which wind-blown water could enter. Moreover, the paint could provide a better seal at the lap. Furthermore, back dressing gives better support for nailing and should reduce splitting in both the butt edge and the thin edge.

Good results were obtained with panels of standard-pattern, untreated material that had been previously tested and then brush-treated at the lap and again exposed to wetting. Though these were not fully equal to the panels made of siding that had been dip-treated, again the results were impressive. Very little water appeared on the back of the siding.

The results of the tests on the untreated panels indicate that the application of water-repellent treatments to existing houses would greatly minimize paint blistering caused by rain water that works in from the outside and thereby save considerably in paint maintenance. The water repellent should be applied generously along the butt edge of the upper course of siding where it lies against the next lower course, so that the fluid can work up into the lap between the boards. Many of the larger lumber dealers stock commercial water repellents.

The studies described above did not include water entrance through end joints, and there were no butt joints in the panels. The end joints were set in white lead, and no leakage was observed. Since it is not common practice to use white lead in the end joints, some leakage may be expected under normal service conditions. The use of the water repellent should be helpful in preventing leakage through butt and end joints.

In the Laboratory tests capillary flow was completely eliminated in test panels made of bevel siding that had been dipped in a water-repellent preservative for 3 minutes. Subsequent tests indicated similar results could be expected with a 10-second dip. The treatment was also effective in preventing the entrance of wind-driven water.

The application of a water repellent along the under side of the butt edge at the lap was effective in reducing capillarity, though not equal in effect to dipping. Nevertheless, these tests indicate that the application of the repellent in this manner to the siding of existing houses would materially reduce the effects of capillary water flow. It would mean better paint performance and reduced maintenance.

In areas of high humidity and long warm seasons, as in some Southern

Figure 8.—The back of this panel of untreated and unpainted siding showed general wetting when water was sprayed on the face of the siding for 4 hours. The excessive wetting of the two bottom boards was due principally to a nail split in the thin edge of the next to bottom board. If the face of the siding had been painted, the amount of water entering at some of the laps would have been reduced so that less wetting would show up on some of the boards than on others.

Figure 9.—The back of this panel of treated but unpainted siding showed no wetting after a 4-hour exposure to water sprayed on the face of the panel.

states, decay often becomes a problem in siding. Under such conditions, water-repellent preservatives serve the added purpose of protecting wood siding from decay, as shown by research at the Southern Forest Experiment Station of the Forest Service, at New Orleans.

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Swelling of Paint Films in Water, II[1]

Absorption and Volumetric Swelling of Bound and Free Films Before and After Weathering

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Previous methods of studying swelling of paint films in water were improved by including measurements of volumetric swellings of both free films and bound films (coatings on glass). The new technique leads to more precise measurements and discloses information about the structure of the paint coatings.

A TECHNIQUE for measuring the volumetric swelling of bound films of house paint coated on glass as well as of free films was developed to supplement the measurements of absorption of water, swelling in area, changes on redrying, and loss of soluble ingredients previously described for free films. Although bound films absorb and swell somewhat less than free films do, films of some paints still display great sensitivity to water. Both artificial and natural weathering usually reduce absorption and swelling below the values for unweathered films; but the reduction takes place during the first few months of natural weathering or the equivalent and, thereafter, remains nearly constant for at least 16 years. Unweathered films swell at least 1 cubic centimeter for each gram of water absorbed; weathered films swell less, sometimes much less than 1 cubic centimeter for a gram of absorbed water. Swelling and redrying or weathering may develop voids within the films that can hold free water that does not contribute to swelling.

Introduction

A previous paper (3) reported measurements of the absorption of water by free films of house paints, the swelling of the films in surface area caused by absorption of water, the shrinking on subsequent redrying, and the loss of soluble ingredients while soaking in water. Some paints were found to swell several times as much as wood does, whereas others swell less than wood. Data were also presented on the effects on absorption and swelling of film thickness, time of contact with water, temperature and acidity or alkalinity of the water, aging of the films before soaking in water, and exposure of the paints to both natural and artificial weathering before testing them in water. But direct measurements of the changes in film thickness were not precise enough to permit calculation of the volumetric swelling.

Since the earlier paper was written, the experimental technique has been improved to measure directly the volume of the paint films before and after soaking in water and after redrying. From the changes in volume and in area, the changes in thickness can be calculated precisely. Volumetric swelling was measured both for free films and for coatings on glass (bound films). Volumetric swelling proves to be even more instructive than swelling in area. Among different paints, the volumetric and the areal swelling are not necessarily proportional to each other. Moreover, the volumetric swelling sometimes reveals changes in the internal structure of paint films that are not evident from the areal swelling.

The volume of a free film of paint was measured by weighing the film in air and again in distilled water (4). The difference in weight was the water displaced. Within the precision possible in this work, it was permissible to consider that a displacement of 1 gram of water at room temperature (70° to 75°) represented a volume of 1 cubic centimeter. The film of paint was weighed in air and in water immediately before immersion in water for the soaking test. Then, at the end of the soaking period, it was weighed in water and again in air after removing free water clinging to the surfaces. Finally, it was weighed in air and water for the third time after it had been redried in a dessicator over calcium chloride. Thus the initial volume, the swollen volume, and the volume after redrying and the densities in each of the three conditions could be calculated. The volume of coatings on glass was determined in a similar way by subtracting the previously determined weights of the glass in air and in water.

By use of a chainomatic balance, it was possible to immerse, weigh, and remove a dry film from the water in 140 to 260 seconds. Tests showed that in 5 minutes, even the most highly absorptive paints take up no more than 1 percent of the water they absorb in 3 days of soaking.

Changes in length and width of the free films were measured before and after swelling and after redrying as in the work previously reported (3). From the volume and area of the film, the thickness at each stage of the soaking tests was easily computed.

Paints and Vehicles Tested

The paints tested were chosen from the list of those used in the experiments on swelling in area previously published. The composition of the paints is expressed by volume in the short notation first described by Browne (1) and more recently described in this journal (2). Two clear vehicles without any pigment were tested; namely, raw linseed oil containing lead-manganese naphthenate drier and bodied linseed oil of viscosity Z6 containing the same kind of drier. Single-pigment paints made in the laboratory were as follows:

Magnesium silicate in raw linseed oil, pigment volume (p/nv) 0.30

[1] A contributed paper.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Basic carbonate white lead in raw linseed oil, paint L, p/nv 0.30
Anatase titanium dioxide in raw linseed oil, paint T_{420}, p/nv 0.30
Zinc oxide in raw linseed oil, paint Z, p/nv 0.30

Of the single-pigment paints, only the white lead paint was a practicable house paint; the others are of scientific interest only. Multiple-pigment paints, all of them practicable house paints but made in the laboratory, were as follows:

Paint TL_{40}, p/nv 0.30, anatase titanium dioxide, basic carbonate white lead, magnesium silicate, and calcium carbonate in raw linseed oil
Paint LZ_{37}, p/nv 0.30, basic carbonate white lead and zinc oxide in raw linseed oil
Paint $TL_{50}Z_{30}$, p/nv 0.30,)
Paint $TL_{30}Z_{25}$, p/nv 0.30,)
Paint $TL_{20}Z_{20}$, p/nv 0.30,)
Paint $TL_{10}Z_{10}$, p/nv 0.30,)
anatase titanium dioxide, basic carbonate white lead, zinc oxide, and magnesium silicate in raw linseed oil; same ingredients but differing proportions
Paint TZ_{20}, p/nv 0.30, anatase and rutile titanium dioxide, zinc oxide, magnesium silicate, and calcium carbonate in raw linseed oil
Paint TZ_{20}, p/nv 0.36, the same pigments as paint TZ_{20}, p/nv 0.30, but in a mixture of raw and bodied linseed oil

Commercial paints of open formula were tested as follows:

No. 1—TL_7Z_{23}, p/nv 0.35, leaded zinc oxide, titanium-calcium, titanium dioxide, and magnesium silicate in raw and bodied linseed oil
No. 2—$(TL_{23}Z_{18})_{134}$, p/nv 0.31, basic carbonate white lead, basic silicate white lead, zinc oxide, titanium dioxide, and magnesium silicate in linseed oil
No. 3—$(TZ_{19})_{126}$, p/nv 0.30, zinc oxide, titanium dioxide, and magnesium silicate in linseed and soya oils
No. 4—$(TZ_{16})_{122}$, p/nv 0.38, zinc oxide, titanium dioxide, and magnesium silicate in bodied linseed oil
No. 5—$T_{112}(re)$, p/nv 0.39, titanium dioxide, mica, magnesium silicate, and aluminum stearate in tung oil varnish and bodied linseed oil

Commercial paints 1 to 4 were chosen because they are widely sold in all parts of the United States and are reasonably representative of the range in composition of the commercial first-grade paints with which the public is familiar. Commercial paint No. 5, although not yet so well known, was of particular interest for this study because it is a so-called breather-type of paint that is unusually resistant to moisture blistering.

Methods of Experiment

Unpigmented oils were applied by brushing in successive coats until enough had been applied, determined by weighing, to form a coating of the desired thickness. Pigmented paints were applied by drawing down manually with a Bird doctor blade over a substrate held firmly on a Bird suction plate. Each paint was applied in a single coat at a predetermined wet-film thickness achieved when necessary by use of suitable shims.

Coatings were allowed to dry in the laboratory near a closed window that faced north. Drying continued for 10 days, after which those to be weathered were mounted in an Atlas Weatherometer or on suitable racks placed on a roof of the Laboratory, where the coatings were exposed to natural weather, facing south and sloped back at an angle of 45° from the vertical. Coatings that were not weathered were tested immediately after the 10-day drying period.

Bound Films (Coatings on Glass): In order to compare the absorption of water and swelling of bound films with free films, a rigid substrate that is not measurably affected by water was needed. Glass was chosen for the purpose. Microscope slides 45 mils thick, 1½ inches wide, and 3 inches long were measured for exact thickness with an Ames dial gage and sorted into matched sets actually 46, 45.5, or 44.5 mils thick, plus or minus 0.2 mil. Close control of slide thickness was necessary to permit control of wet-film thickness while applying paint with the doctor blade. Each of the selected microscope slides was marked with an identification number, carefully cleaned and dried in a dessicator over calcium chloride, and then weighed in air and again when submerged in distilled water at the temperature of the room in order to determine its volume by displacement.

After the coatings on glass had been applied and had dried for 10 days, those for testing before weathering were promptly subjected to the soaking test. The others were weighed to determine the initial coating weight. They were then fastened by suitable clips to aluminum-painted plywood backboards of a size to fit the slots in the drum of an Atlas Weatherometer, and the artificial weathering was started. For the purpose of these experiments, the artificial-weathering cycle consisted of constant exposure to visible and ultraviolet light from a flaming carbon arc filtered through Corex D glass, which passes only that portion of the ultraviolet spectrum that is present in normal sunshine out of doors. As the Weatherometer drum rotated, the test specimens passed three times an hour under specially designed sprays that wet the painted surfaces gently with a fine mist of water in sufficient quantity to drain down and drip copiously from the bottom edges of the specimens. After passing the sprays, the water left clinging to the paint evaporated before the specimens moved more than halfway around to the position of the water sprays.

Test data are given in tables 1, 2, 3, and 4. When the data for tables 1 and 3 were obtained, Madison city water, which is very hard, was supplied to the sprays in the Weatherometer. As will be discussed farther on, this led to false results with some paints for the loss in weight during weathering. For that reason, the Weatherometer was later equipped with a tank and pump to supply distilled water to the sprays. The data in table 2 were obtained in the revised Weatherometer.

One set of specimens was exposed in the Weatherometer until the watt-hour meter registered 600 kilowatt-hours, which required about 7½ days. A second set of specimens was exposed for 1,200 kilowatt-hours, or about 15 days. On removal from the Weatherometer, the specimens were dried over calcium chloride and submitted to the soaking test. From the weight before exposure in the Weatherometer and the first weighing in air to start the soaking test, the change in weight of the paint coating during artificial weathering was computed.

Free Films: The paints and oils that were tested as films bound on glass, where the changes in volume necessarily took place entirely by changes in thickness of coating, were tested also as free films that could change in all three dimensions. The free films were prepared by spreading the paints as coatings on gummed paper that had previously been saturated with linseed oil and allowed to dry. For any 1 paint, the coatings on glass and those on gummed paper were always made on the same day, and the 2 types of specimens were taken through the program of exposure and testing contemporaneously. It was practicable to expose the coatings on gummed paper in the Weatherometer without loss of adhesion because the periods of exposure to water spray were too short for the dampness to penetrate through the coatings to soften the layer of gum.

The free films were stripped from the gummed paper after the 10-day drying period for unweathered specimens or after exposure in the Weatherometer by soaking in water for a few minutes until the gum was dissolved. From the free films, test specimens 1½ by 2½

Table 1.--Data for bound films (coatings on glass) of 2 vehicles and 8 paints, each in 2-coating thicknesses, before and after artificial weathering--changes in density while drying and while weathering, changes in weight while weathering (hard water used in Weatherometer water sprays), absorption of water, volumetric swelling, and swelling efficiency when soaked in distilled water for 3 days, changes in volume on redrying, and weight of soluble ingredients lost while soaking

Paint or clear vehicle (density of nonvolatile while liquid)	Time exposed to artificial weathering	Weight change while weathering S_1/V_o	Before soaking: Density	Before soaking: Film thickness T_o	Absorption of water A/V_o	Swelling in volume ΔV_s	Swelling efficiency $\Delta V_s V_o/A$	Redried: change in volume ΔV_r	Weight loss while soaking S_2/V_o
	Days	Percent		Mils	Percent	Percent	Percent	Percent	Percent
Raw linseed oil (0.933)	0		1.15	2.7	17.5	18.3	104	-3.7	4.6
	0		1.11	5.5	10.3	10.7	104	-2.6	2.8
	7-1/2	-33.1	1.20	2.0	27.6	25.5	93	-4.2	7.6
	7-1/2	-16.5	1.15	5.1	10.8	9.9	92	-2.2	3.5
	15	-72.4	1.25	1.4	40.3	38.0	94	-6.6	8.1
	15	-27.2	1.16	5.1	10.9	10.3	94	-2.6	2.9
Bodied linseed oil, Z6 viscosity (0.970)	0		1.12	2.5	10.6	12.0	113	-2.9	3.1
	0		1.10	5.3	5.7	6.7	117	-1.7	1.5
	7-1/2	-22.1	1.19	2.1	26.8	23.8	89	-3.1	6.2
	7-1/2	-13.2	1.15	4.6	13.3	11.5	87	-1.1	3.2
	15	-42.6	1.23	1.8	38.0	34.5	91	-3.3	5.4
	15	-18.3	1.16	4.6	13.4	12.5	94	-1.9	2.8
Magnesium silicate, p/nv 0.30 (1.515)	0		1.70	3.3	40.7	41.9	103	-2.9	3.2
	0		1.64	6.4	17.0	17.8	105	-1.5	1.1
	7-1/2	-11.0	1.82	2.9	11.2	9.4	84	-2.0	3.8
	7-1/2	-5.1	1.73	6.5	7.4	6.6	89	-1.0	1.6
	15	-19.4	1.94	2.6	10.0	7.9	79	-2.8	4.2
	15	-8.1	1.74	6.4	7.0	6.2	89	-1.1	1.2
Basic carbonate white lead, L, p/nv 0.30 (2.705)	0		3.00	3.5	8.1	8.7	107	-2.0	3.0
	0		2.90	6.8	4.4	5.3	120	-1.3	1.0
	7-1/2	-6.3	3.22	3.0	17.0	15.6	92	-1.8	3.2
	7-1/2	-3.8	3.02	6.9	7.7	7.2	94	-.7	1.3
	15	-12.2	3.39	2.7	18.3	15.8	87	-1.5	3.6
	15	-5.3	3.08	6.5	10.6	10.0	94	-1.1	1.1
Titanium dioxide, anatase type, T_{420}, p/nv 0.30 (1.820)	0		2.02	2.6	23.5	24.9	106	-3.0	3.4
	0		1.92	6.8	7.3	8.2	112	-1.3	.8
	7-1/2	-29.5	2.26	2.6	10.5	8.6	82	-1.3	2.7
	7-1/2	-7.2	2.00	7.1	4.6	3.2	70	-.6	1.0
	15	-33.0	2.40	2.6	13.0	10.2	79	-3.0	4.8
	15	-12.3	2.08	6.7	4.6	3.6	78	-1.1	1.3
Zinc oxide, Z, p/nv 0.30 (2.345)	0		2.51	2.8	62.7	62.0	99	+1.2	2.3
	0		2.44	6.1	21.9	22.5	103	-.4	.1
	7-1/2	+2.8	2.57	2.2	26.9	21.9	82	-.8	2.7
	7-1/2	+2.3	2.48	6.8	9.2	8.4	91	0	.7
	15	-2.1	2.74	2.8	18.5	16.9	91	-1.8	4.2
	15	+2.9	2.52	6.5	8.3	8.1	98	-1.5	.8
Titanium-lead-zinc, $TL_{50}Z_{30}$, p/nv 0.30 (2.370)	0		2.56	3.8	26.6	27.0	101	-.4	1.1
	0		2.46	8.3	17.5	17.9	102	-.2	0
	7-1/2	+2.0	2.64	3.8	14.0	12.7	91	-1.1	1.5
	7-1/2	+3.3	2.50	8.2	6.1	5.4	89	-.6	1.5
	15	+7.1	2.70	3.9	13.4	7.9	59	-1.9	3.1
	15	+4.4	2.55	8.0	6.5	5.9	91	-.1	.4
Titanium-zinc, TZ_{20}, p/nv 0.36 (1.870)	0		2.00	3.6	31.6	31.3	99	-1.3	1.4
	0		1.96	6.7	18.4	18.8	102	-.8	.4
	7-1/2	+7.6	2.05	3.5	18.9	16.4	87	-2.4	2.8
	7-1/2	+3.2	2.01	6.6	11.7	11.2	96	-1.5	1.7
	15	+12.1	2.14	3.4	21.2	19.1	90	-2.0	3.9
	15	+5.0	2.05	6.5	13.1	12.2	93	-.5	1.0
Commercial paint No. 1, TL_7Z_{23}, p/nv 0.35 (2.005)	0		2.14	4.4	30.4	30.5	100	-1.5	1.9
	0		2.11	7.9	18.8	19.2	102	-1.0	.6
	7-1/2	+5.7	2.18	4.7	20.1	18.9	94	-8.3	8.0
	7-1/2	+2.0	2.15	8.8	8.1	7.3	90	-.5	1.2
	15	+2.0	2.28	4.3	14.5	12.9	89	-1.2	3.4
	15	+2.1	2.18	8.5	8.2	7.7	94	-.6	.9
Commercial paint No. 5, T_{112}(re), p/nv 0.39 (1.688)	0		1.85	3.1	16.3	17.2	106	-1.6	1.5
	0		1.82	4.9	10.6	11.3	107	-1.6	1.0
	7-1/2	-4.9	1.92	3.2	9.0	7.7	86	-1.9	3.1
	7-1/2	-3.9	1.87	5.3	7.6	6.4	84	-1.0	1.7
	15	+4.3	2.00	3.1	9.9	5.5	56	-1.4	4.3
	15	+2.1	1.93	5.2	6.3	3.2	51	-.4	2.1

inches were cut with a template and razor blade. Each specimen was marked in black drawing ink with an identification mark and suitable reference lines for measuring length and width under a traveling microscope. The specimens were then dried over calcium chloride before starting a soaking test.

Coatings on gummed paper have the disadvantage that the changes in weight of the coatings while undergoing weathering cannot be measured reliably because the paper, the linseed oil in the paper, and perhaps the gum undergo changes in weight at the same time. In later work, therefore, coatings for exposure either in the Weatherometer or to natural weathering were spread on tinplate. The tinplate specimens could be weighed before and after exposure with reasonable assurance that any change in weight occurred in the coating. After exposure and reweighing, the coatings were stripped from the tin-

Table 2.--Data for free films of 2 vehicles, 11 laboratory-made, and 5 commercial paints before and after artificial weathering for 15 days and after natural weathering for 6 months and for 12 months--losses in weight while weathering (distilled water used in Weatherometer water sprays), changes in density, absorption of water, swelling in volume, area, and thickness and swelling efficiency when soaked in distilled water for 3 days, changes in volume, area, and thickness on redrying, and weight of soluble ingredients lost while soaking

Paint or clear vehicle (density of nonvolatile vehicle while liquid)	Weathering		Weight loss while weathering	Before soaking		Absorption of:	Swelling increase			Swelling efficiency	Redried change			Weight loss while soaking
	Kind	Time	S_1/V_o	Density	Film thickness T_o	water A/V_o	In volume ΔV_s	In area ΔQ_s	In thickness ΔT_s	$\Delta V_s V_o/A$	In volume ΔV_r	In area ΔQ_r	In thickness ΔT_r	S_2/V_o
		Mo.	Percent		Mils	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Raw linseed oil (0.933)	None	0		1.11	3.1	21.8	22.0	9.8	10.8	101	-6.0	-4.9	-1.3	5.8
	Artificial	1/2	(1)	1.17	3.7	20.4	20.5	4.4	15.5	100	-2.2	-1.7	+.3	2.9
	Natural	6	80.4	1.16	2.7	24.2	16.6	8.7	9.7	69	-2.0	-3.8	+1.9	6.1
	....do....	12	92.0	1.22	2.5	25.0	28.3	3.3	14.4	113	-10.4	-2.5	-8.0	6.8
Bodied linseed oil, Z6 viscosity (0.970)	None	0		1.10	3.6	9.0	9.2	6.1	1.4	102	-4.9	-2.6	-2.2	5.1
	Artificial	1/2	(1)	1.16	4.1	28.1	27.5	10.1	14.9	98	-.7	+2.1	+.2	1.8
	Natural	6	41.4	1.19	3.2	7.5	8.3	4.1	1.3	110	-3.3	-.1	-2.8	2.8
	....do....	12	41.1	1.19	3.3	8.2	7.7	2.4	2.1	94	-3.2	-1.1	-1.5	3.1
Magnesium silicate, p/nv 0.30 (1.515)	None	0		1.68	2.9	56.2	56.1	15.9	31.5	100	-3.8	+2.2	-6.1	4.5
	Artificial	1/2	19.0	1.89	2.4	9.9	9.8	5.0	6.7	99	-2.1	-3.4	+.1	3.4
	Natural	6	33.8	1.80	3.9	6.4	6.7	2.2	2.5	105	-2.5	-.3	-2.3	2.1
	....do....	12	39.6	1.81	3.8	6.7	6.4	1.6	2.6	96	-2.6	0	-2.6	1.7
Basic carbonate white lead, L, p/nv 0.30 (2.705)	None	0		2.84	3.9	10.7	10.8	6.0	1.6	101	-3.3	+1.0	-3.6	4.8
	Artificial	1/2	21.0	3.21	5.5	12.4	12.3	2.0	10.0	99	-1.2	-.8	+.2	1.8
	Natural	6	26.5	3.28	3.9	11.0	8.8	3.9	5.1	80	+2.0	+.4	+1.5	2.7
	....do....	12	28.3	3.28	4.1	10.8	6.9	3.0	3.2	64	-.9	0	-1.0	3.5
Titanium-lead, TL_{40}, p/nv 0.30 (2.010)	None	0		2.22	4.0	29.3	29.9	12.7	11.8	102	-3.9	+1.6	-5.3	5.1
	Artificial	1/2	(2)											
	Natural	6	51.6	2.67	3.1	27.2	26.3	9.1	17.0	97	-.3	+2.7	-2.6	1.8
	....do....	12	53.7	2.65	3.3	28.2	27.0	8.4	16.4	96	-.8	+1.3	-2.1	2.3
Titanium dioxide, anatase type, T_{420}, p/nv 0.30 (1.820)	None	0		2.02	2.7	25.6	25.3	13.5	6.9	99	-4.1	+1.0	-4.7	5.2
	Artificial	1/2	55.1	2.12	5.6	10.2	9.5	2.5	6.2	93	-1.3	-.7	0	2.3
	Natural	6	85.2	2.32	2.9	20.9	18.1	7.4	8.8	87	-2.4	-.8	-1.4	2.9
	....do....	12	107	2.39	2.8	12.8	9.1	3.2	3.5	71	-2.3	-.9	-1.1	4.7
Zinc oxide, Z, p/nv 0.30 (2.345)	None	0		2.48	3.7	74.6	74.6	42.7	20.0	100	-3.9	+9.4	-12.0	5.6
	Artificial	1/2	12.1	2.77	2.2	40.0	32.4	11.7	18.9	81	+.6	+2.2	-.5	8.2
	Natural	6	16.3	2.54	4.1	44.4	38.3	14.5	20.9	86	+29.4	+2.6	+26.5	7.5
	....do....	12	15.8	2.58	4.0	33.8	29.7	14.6	12.6	88	-.8	+4.3	-4.9	7.3
Lead-zinc, LZ_{37}, p/nv 0.30 (2.563)	None	0		2.74	3.9	68.0	81.0	32.6	24.0	119	-2.8	+6.4	-8.5	4.6
	Artificial	1/2	7.7	2.84	4.2	37.6	34.6	20.0	32.7	92	-2.0	+7.6	-1.7	1.7
	Natural	6	20.7	2.94	4.0	42.5	37.8	19.5	14.9	89	+22.5	+2.6	+20.0	7.1
	....do....	12	21.8	2.90	4.1	41.3	36.6	19.3	12.3	89	-3.1	(3)	.....	8.3
Titanium-lead-zinc, $TL_{50}Z_{30}$, p/nv 0.30 (2.370)	None	0		2.52	3.9	61.2	60.5	33.5	19.3	99	-2.0	+7.7	-9.0	3.8
	Artificial	1/2	13.0	2.74	3.4	36.6	34.8	13.7	34.0	95	-1.0	+4.2	-.9	2.5
	Natural	6	16.3	2.69	3.9	38.1	37.0	17.2	14.6	97	-2.9	+5.0	-7.4	6.9
	....do....	12	20.2	2.68	4.0	36.6	34.5	18.0	11.4	94	-3.0	+5.9	-8.2	7.1

plate by floating them face down on mercury until the tin became amalgamated and the coatings could be stripped off. The free films were then cut to size, marked, and equilibrated over calcium chloride in preparation for soaking tests.

Methods of Expressing Results

During exposure to natural or artificial weathering, there is normally a loss of weight of coatings by leaching of water-soluble ingredients and sometimes by erosion (chalking). Some paints reported in table 1 gained in weight during artificial weathering for a reason that is explained farther on. In either case, the change in weight, which was the difference in weight of coating in grams immediately before exposure and afterward, is represented by the symbol S_1. There was a further loss in weight from all coatings and films during the 3-day soaking test that was revealed by the difference in weight in air just before immersion in water and the weight in air after redrying over calcium chloride. This loss in weight in grams from leaching of soluble ingredients is represented by the symbol S_2.

All coatings and films absorbed water during the 3-day soaking test. The absorption of water in grams, represented by A, was the difference between the weight in air on removal from water and the weight after redrying over calcium chloride. If the initial rather than the final dry weight were taken for the subtrahend, the absorption would be underestimated by the weight of soluble ingredients lost during the soaking. By the method used, there is still a small error from loss of volatile ingredients other than water during the period of redrying in a dessicator, but such loss of volatile matter is much less than the loss of soluble substances while soaking.

The great variation in density among the paints and vehicles studied raises a problem of finding a meaningful method of expressing comparative results for absorption of water, A, and the losses, S_1 and S_2. In the previous paper (3), A and S_2 were reported in percent by weight of the oil present in the film calculated on the assumption that the film at the time of test retained the same percentage of oil as the nonvolatile portion of the liquid paint from which the film had been made. The assumption is at best a reasonable approximation for unweathered films and becomes decreasingly reliable as the films are weathered. Volumetric measurements offer a much better basis of expression; namely, the volume in cubic centimeters of the film or coating at the beginning of the soaking test, represented by the symbol V_o. Accordingly, the absorption of water is now reported as $(A/V_o) \times 100$, which is the percent by volume if 1 gram of water is taken as 1 cubic centimeter. The losses S_1 and S_2 are expressed similarly; $(S/V_o) \times 100$, or the grams of substance of unknown composition lost per 100 cubic centimeters of film.

During the 3-day soaking in water the initial volume V_o increased to a larger volume V_s; and when the film was redried, the volume shrank to V_r. As a rule, V_r was less than V_o, presumably by the volume of soluble ingredients leached out while soaking. In such cases, the percent swelling in volume, $\triangle V_s$, was calculated as $100\ (V_s - V_r)/V_o$; and it was observed that the density of the redried film returned nearly to the density before soaking or

Table 2.--Data for free films of 2 vehicles, 11 laboratory-made, and 5 commercial paints before and after artificial weathering for 15 days and after natural weathering for 6 months and for 12 months--losses in weight while weathering (distilled water used in Weatherometer water sprays), changes in density, absorption of water, swelling in volume, area, and thickness and swelling efficiency when soaked in distilled water for 3 days, changes in volume, area, and thickness on redrying, and weight of soluble ingredients lost while soaking--continued

Paint or clear vehicle (density of nonvolatile while liquid)	Weathering		Weight loss while weathering S_1/V_o	Before soaking		Absorption of water A/V_o	Swelling increase			Swelling efficiency $\Delta V_s V_o/A$	Redried change			Weight loss while soaking S_2/V_o
	Kind	Time		Density	Film thickness T_o		In volume ΔV_s	In area ΔQ_s	In thickness ΔT_s		In volume ΔV_r	In area ΔQ_r	In thickness ΔT_r	
		Mo.	Percent		Mils	Percent:	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Titanium-lead-zinc, $TL_{30}Z_{25}$, p/nv 0.30 (2.110)	None	0		2.25	3.9	69.2	67.8	33.3	24.8	98	-1.5	+8.6	-9.4	4.8
	Artificial	1/2	9.2	2.40	4.4	32.1	31.1	15.0	30.7	97	-.4	+4.6	-.2	.9
	Natural	6	11.1	2.38	5.3	37.7	35.5	16.6	14.8	94	-1.6	(3)		6.5
	....do....	12	24.3	2.40	3.9	39.2	35.3	15.1	16.0	90	-1.7	+5.4	-6.9	7.4
Titanium-lead-zinc, $TL_{20}Z_{20}$, p/nv 0.30 (1.960)	None	0		2.10	3.7	71.0	70.5	31.5	28.6	99	-1.8	+8.0	-8.9	3.0
	Artificial	1/2	10.3	2.27	4.3	42.4	40.1	18.3	40.0	95	+.9	+7.3	+.9	1.8
	Natural	6	19.1	2.20	3.6	49.0	44.1	15.2	25.2	90	+14.5	+2.9	+11.6	5.7
	....do....	12	15.6	2.22	4.1	41.4	38.2	14.3	19.3	93	-2.1	+4.6	-6.4	6.3
Titanium-lead-zinc, $TL_{10}Z_{10}$, p/nv 0.30 (1.900)	None	0		1.92	4.1	59.3	59.5	27.3	24.0	100	-2.4	+6.7	-8.7	3.7
	Artificial	1/2	12.7	2.15	3.9	38.8	36.8	15.6	35.8	95	+1.2	+8.6	+1.0	1.5
	Natural	6	27.5	2.03	3.4	54.6	47.0	18.2	24.3	86	+29.2	+6.0	+22.5	7.6
	....do....	12	27.8	2.06	3.8	43.4	40.6	13.8	22.1	94	-2.1	+4.3	-6.0	5.8
Titanium-zinc, TZ_{20}, p/nv 0.30 (1.728)	None	0		1.86	4.0	118	109	56.7	31.8	93	-2.3	+17.4	-17.2	5.3
	Artificial	1/2	8.2	1.93	4.6	48.3	45.7	21.0	45.5	95	+2.2	+10.8	+2.2	1.6
	Natural	6	16.6	1.95	4.4	69.0	68.6	28.4	31.6	99	+30.9	(3)		6.4
	....do....	12	20.0	1.95	4.1	61.8	60.1	27.2	23.2	97	-3.6	+11.6	-13.5	7.4
Commercial paint No. 1, TL_7Z_{23}, p/nv 0.30 (2.005)	None	0		2.16	3.4	92.0	91.0	36.3	37.3	99	-3.4	+10.5	-12.4	7.5
	Artificial	1/2	(1)	2.26	2.2	46.9	45.4	18.3	22.4	97	-.9	+5.8	-6.4	4.2
	Natural	6	15.5	2.24	4.9	63.0	59.7	27.5	25.0	95	+1.3	+13.4	-10.6	5.8
	....do....	12	18.1	2.25	5.2	48.7	46.6	19.8	22.2	96	-1.1	+9.9	-9.6	5.0
Commercial paint No. 2, $(TL_{23}Z_{18})_{134}$, p/nv 0.31 (1.960)	None	0		2.10	3.6	72.4	71.4	25.8	33.9	99	-3.0	+8.0	-9.9	4.9
	Artificial	1/2	(2)											
	Natural	6	11.3	2.19	5.8	47.2	45.2	15.1	26.5	96	+1.3	+5.2	-3.4	2.4
	....do....	12	22.0	2.21	4.7	46.0	42.7	15.4	23.4	93	-.4	+7.5	-7.4	3.4
Commercial paint No. 3, $(TZ_{19})_{126}$, p/nv 0.30 (1.745)	None	0		1.87	3.1	90.5	92.0	22.1	53.8	102	-4.7	+4.8	-9.1	9.5
	Artificial	1/2	(2)											
	Natural	6	13.4	1.95	4.8	82.0	77.7	7.5	65.5	95	+15.7	+1.0	+15.1	8.1
	....do....	12	16.5	1.95	4.9	38.8	36.2	6.7	25.3	94	-2.7	+1.8	-4.0	9.0
Commercial paint No. 4, $(TZ_{16})_{122}$, p/nv 0.38 (2.000)	None	0		2.18	3.4	84.2	84.3	44.1	22.0	100	-8.4	+13.5	-18.5	19.9
	Artificial	1/2	(2)											
	Natural	6	18.4	2.23	3.8	41.6	27.3	8.4	18.3	66	+2.5	-.2	+2.7	34.5
	....do....	12	21.2	2.26	3.9	42.5	40.3	8.5	24.1	95	-6.0	-.5	-5.4	27.4
Commercial paint No. 5, T_{112}(re), p/nv 0.39 (1.688)	None	0		1.92	1.6	23.2	24.1	5.5	14.5	104	-3.7	-.4	-4.0	4.2
	Artificial	1/2	(1)	2.08	1.6	11.0	4.0	2.0	1.3	36	+1.2	0	+1.2	6.4
	Natural	6	48.5	2.06	1.9	10.3	9.4	2.5	4.7	91	-2.5	+.3	-2.6	2.9
	....do....	12	62.6	2.06	2.0	10.1	9.7	2.0	4.1	96	-3.3	-.6	-2.6	3.2

[1] Not determined.

[2] These paints were not tested after artificial weathering with distilled water in the Weatherometer sprays.

[3] Data lacking because the redried films were too badly curled and too brittle to permit measurements.

became slightly greater. But with films of some paints, the redried volume V_r was greater than the initial volume V_o, and the density after redrying remained significantly less than the density before soaking, despite loss of soluble ingredients. To avoid gross underestimation in such cases, the volumetric swelling was calculated by the formula $\triangle V_s = 100(V_s - V_o)/V_o$. The percentage change in volume after redrying was always calculated from the formula $\triangle V_r = 100(V_r - V_o)/V_o$. It was negative or positive accordingly as V_r was greater or less than V_o.

The relation between the percent absorption, A/V_o, and the volumetric swelling, $\triangle V_s$, was conveniently studied by computing the swelling efficiency, which was $\triangle V_s$ divided by A/V_o times 100, expressed in percent. As a rule, the swelling efficiency was not far from 100 percent, which meant that each gram of water absorbed increased the volume of the film by 1 cubic centimeter. After weathering, the swelling efficiency tended to decrease somewhat, and for a few paints it decreased markedly. There are paints not included in these tests for which the swelling efficiency is less than 100 percent even before weathering. Low values of swelling efficiency indicate that the film contains voids that can take up water without causing any swelling, a condition that was predicted from theoretical considerations by MacGregor (7).

Changes in area of free films were calculated from the changes in length and width between lines ruled on the surface of the films about an inch apart in the central portion of the films. Curling at the edges of films that swell greatly made it impracticable to make measurements between edges. It was shown in the previous paper that films of many paints swell more across the grain of the paint, determined by the last direction of flow of the paint during application, than with the grain. After computing the percentage change in area of the marked portion of the films, the change in total area was calculated on the assumption that the whole film changed in the same proportion as its marked central portion. Taking Q_o, Q_s, and Q_r as the areas before soaking, after soaking, and after redrying, respectively, the areal swelling, $\triangle Q_s$, and the change in area on redrying, $\triangle Q_r$, were computed analogously to the changes in volume from the formulas: $\triangle Q_s = 100(Q_s - Q_r)/Q_o$ if Q_r was less than Q_s, or $\triangle Q_s = 100(Q_s - Q_o)/Q_o$ if Q_r was greater than Q_o and $\triangle Q_r = 100(Q_r - Q_o)/Q_o$.

The thickness of the film in mils (1 mil = 0.001 inch) before soaking was calculated from the volume and area, $T_o = 61\ V_o/Q_o$ where V_o is in cu. cms., Q_o in square inches, and 61 is a con-

Table 3.--Data for free films of 2 vehicles and 8 paints, each in 2 coating thicknesses, before and after artificial weathering--changes in density while drying and while weathering, absorption of water, swelling in volume, area, and thickness and swelling efficiency when soaked in distilled water for 3 days, changes in volume, area, and thickness on redrying, and weight of soluble ingredients lost while soaking

Paint or clear vehicle (density of nonvolatile while liquid)	Time exposed to artificial weathering	Before soaking: Density	Before soaking: Film thickness T_o	Absorption of: water A/V_o	Swelling increase: In volume ΔV_s	Swelling increase: In area ΔQ_s	Swelling increase: In thickness ΔT_s	Swelling efficiency $\Delta V_s V_o/A$	Redried change: In volume ΔV_r	Redried change: In area ΔQ_r	Redried change: In thickness ΔT_r	Weight loss while soaking S_2/V_o
	Days		Mils	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Raw linseed oil (0.933)	0	1.11	3.1	21.8	22.0	9.8	10.8	101	-6.0	-4.9	-1.3	5.8
	0	1.11	5.6	10.8	11.0	6.5	1.1	102	-5.2	-1.6	-3.6	5.2
	7-1/2	1.20	1.7	45.6	38.3	25.8	21.2	84	+.4	-14.4	+17.0	9.4
	7-1/2	1.17	3.9	16.1	16.5	6.2	6.6	103	-3.5	+1.2	-4.6	5.0
	15	(1)										
	15	1.17	3.7	20.4	20.5	4.4	15.5	100	-2.2	-1.7	+.3	2.9
Bodied linseed oil, Z6 viscosity (0.970)	0	1.11	3.6	9.0	9.2	6.1	1.4	102	-4.9	-2.6	-2.2	5.1
	0	1.10	5.4	7.5	8.0	5.4	1.3	107	-3.7	-2.2	-1.5	3.4
	7-1/2	1.18	3.1	45.2	44.8	16.1	23.1	99	-1.5	+3.7	-4.9	4.0
	7-1/2	1.15	4.7	18.5	18.6	6.2	9.5	100	-2.3	-.3	-2.3	3.2
	15	(1)										
	15	1.16	4.1	28.1	27.5	10.1	14.9	98	-.7	+2.1	+.2	1.8
Magnesium silicate, p/nv 0.30 (1.515)	0	1.68	2.9	56.2	56.1	15.9	31.5	100	-3.8	+2.2	-6.1	4.5
	0	1.65	6.7	33.0	33.1	11.8	16.8	100	-2.8	+1.1	-4.0	2.9
	7-1/2	1.82	2.6	7.2	7.0	3.2	1.9	97	-2.1	-.6	-1.9	3.4
	7-1/2	1.71	6.5	5.1	5.3	1.7	3.1	104	-.6	0	-.6	.6
	15	1.89	2.4	9.9	9.8	5.0	6.7	99	-2.1	-3.4	+.1	3.4
	15	1.74	6.3	5.8	5.2	1.9	2.9	90	-.5	0	+.3	.6
Basic carbonate white lead, L, p/nv 0.30 (2.705)	0	2.98	2.8	10.0	9.2	4.7	1.1	92	-3.9	-.2	-3.6	6.1
	0	2.98	6.4	6.5	6.6	3.6	2.3	101	-2.0	-1.0	-1.1	2.6
	7-1/2	3.28	2.5	19.1	19.1	2.0	15.7	100	-1.8	-.8	-1.2	2.9
	7-1/2	3.10	6.1	7.5	7.9	1.8	4.9	105	-1.7	-.3	-1.5	1.8
	15	3.47	2.1	13.4	10.7	1.8	10.0	80	-.1	-.8	+.6	3.6
	15	3.21	5.5	12.4	12.3	2.0	10.0	99	-1.2	-.8	+.2	1.8
Titanium dioxide, anatase type, T_{420}, p/nv 0.30 (1.820)	0	2.02	2.7	25.6	25.3	13.5	6.9	99	-4.1	+1.0	-4.7	5.2
	0	1.97	6.7	12.2	12.5	7.5	3.4	102	-2.6	-1.0	-1.9	2.5
	7-1/2	2.34	2.1	8.8	9.6	3.6	5.3	109	-1.7	-1.0	-1.0	3.8
	7-1/2	2.07	6.0	4.3	4.2	2.2	1.7	98	-.5	-.3	-.3	1.1
	15	(1)										
	15	2.12	5.6	10.2	9.5	2.5	6.2	93	-1.3	-.7	0	2.3
Zinc oxide, Z, p/nv 0.30 (2.345)	0	2.46	2.5	96.7	96.5	65.9	16.8	100	-3.5	+24.6	-22.4	6.3
	0	2.46	6.2	46.4	46.2	24.9	16.0	100	-1.5	+5.1	-6.0	1.9
	7-1/2	2.70	2.4	46.2	41.0	13.7	24.6	89	+2.6	+2.8	0	6.1
	7-1/2	2.51	6.2	9.2	9.4	4.5	4.7	102	0	+.4	-.5	.6
	15	2.77	2.2	40.0	32.4	11.7	18.9	81	+.6	+2.2	-.5	8.2
	15	2.53	5.7	10.0	8.8	3.0	5.3	88	-.4	+.1	-.2	1.1
Titanium-lead-zinc, $TL_{50}Z_{30}$, p/nv 0.30 (2.370)	0	2.53	2.9	61.5	61.1	38.0	15.6	99	-2.1	+10.2	-10.7	3.7
	0	2.51	7.1	30.8	30.8	15.2	12.4	100	-1.3	+1.8	-3.1	1.3
	7-1/2	2.65	2.8	27.3	32.2	11.4	17.7	118	-.9	+3.1	-4.0	2.5
	7-1/2	2.57	7.0	10.0	9.7	5.6	3.6	97	-.4	+1.0	-1.3	.5
	15	2.71	2.6	33.2	30.9	17.4	8.5	93	+.8	+5.6	-2.3	2.8
	15	2.58	6.6	8.5	7.9	3.3	5.0	93	0	-.1	+.5	.5
Titanium-zinc, TZ_{20}, p/nv 0.36 (1.870)	0	2.00	2.5	90.3	86.8	58.5	18.0	96	-.3	+20.1	-17.0	5.0
	0	1.97	5.6	44.9	44.4	23.8	15.3	99	-1.6	+4.6	-5.7	2.3
	7-1/2	2.08	2.3	60.8	58.8	18.8	33.8	97	+15.3	+4.6	+10.0	2.9
	7-1/2	2.00	5.6	16.9	16.1	5.8	10.0	95	-.2	-.5	+.2	1.1
	15	2.07	2.2	71.0	69.3	21.4	39.8	98	+4.7	+6.0	+.5	2.9
	15	2.03	5.4	18.4	17.6	6.7	10.8	96	+.5	+1.3	0	1.0
Commercial paint No. 1, TL_7Z_{23}, p/nv 0.30 (2.005)	0	2.15	2.5	71.2	67.5	36.6	22.7	95	+1.8	+10.1	-7.5	6.9
	0	2.15	5.6	39.1	38.8	15.3	19.0	99	-1.8	+2.5	-4.1	2.8
	7-1/2	2.25	2.3	43.0	43.6	20.3	18.7	101	-.8	+7.4	-7.7	2.1
	7-1/2	2.18	5.8	12.2	12.0	4.6	6.7	98	-.3	+.5	-.9	.8
	15	2.26	2.2	46.9	45.4	18.3	22.4	97	-.9	+5.8	-6.4	4.2
	15	2.18	5.4	14.8	14.0	6.2	7.2	95	-.5	+.9	+.2	1.3
Commercial paint No. 5, T_{112}(re), p/nv 0.39 (1.688)	0	1.92	1.6	23.2	24.1	5.5	14.5	104	-3.7	-.4	-3.6	4.2
	0	1.84	3.9	19.9	20.5	4.0	14.1	103	-2.5	-.4	-2.3	2.3
	7-1/2	2.03	1.6	7.6	.6	2.3	0	8	-3.5	-.2	-3.2	3.5
	7-1/2	1.89	4.3	7.0	6.4	1.6	3.7	91	-1.5	-.3	-1.6	2.0
	15	2.08	1.6	11.0	4.0	2.0	1.3	36	+1.2	0	+1.2	6.4
	15	1.92	4.2	7.6	4.5	2.0	2.4	59	+1.0	0	+1.0	2.5

[1] These films were too badly damaged by weathering to be stripped from the gummed paper substrate as free films suitable for soaking tests.

version factor to give the answer in mils. For films bound on glass, the thickness necessarily changed during soaking and redrying by the same percentage as the change in volume, provided the coating remained attached to the glass substrate. But free films usually change in area as well as in thickness. The thickness when swollen was therefore calculated from the formula

$T_s = 61\ V_s/Q_s$, and the thickness after redrying from the formula

$T_r = 61\ V_r/Q_r$. The percent change in thickness on swelling was

$\Delta T_s = 100(T_s - T_o)/T_o$, and the percent change on redrying was

$\Delta T_r = 100(T_r - T_o)/T_o$.

Comparison of Bound and Free Films Before and After Artificial Weathering

Table 1 records the results of experiments with bound films (coatings on glass), and table 3 the contemporaneous results with free film of the same vehicle and paints. Each vehicle or paint was tested both bound and free in two different thicknesses of film because thin films change more rapidly or to greater extent than thick films. In making comparisons, therefore, both thick and thin films should be considered and allowance made for variations in thickness.

Changes in Density: The 10-day-old coatings of all of the vehicles and paints were markedly higher in density than the nonvolatile portion of the liquid coating material from which they were made. Part of the increased density came from absorption of oxygen while drying, but others (4, 5) have shown that most of it came from contraction in volume, which for raw linseed oil after 10 days may amount to nearly 13 percent (4). On weathering, the density of the coatings continued to increase materially. Part of the increase in density on weathering of the pigmented coatings may be attributed to loss of volatile and soluble products of decomposition of the linseed oil vehicle, and to the leaving behind of a higher proportion of the pigments, which are much denser than the vehicle. But there was also some loss of pigment by chalking or by leaching of soluble salts formed by reaction of some pigments with decomposition products of the vehicle. After allowance for such losses, however, it is clear that much of the increase in density was due to further contraction in volume of the coatings.

The increase in density while drying was often slightly more for thin coatings than for thick ones. The difference was greater for coatings on glass than for coatings on gummed paper. Such effect of coating thickness was to be expected because the oxygen necessary for drying enters the coating at its surface, affects the top of the coating sooner than the bottom, and takes longer to penetrate to the bottom of a thick than of a thin coating. The gummed paper substrate may have been somewhat permeable to oxygen, whereas the glass substrate was not. On weathering, thin coatings always gained in density more rapidly than thick coatings; particularly so when the coating contained opaque pigments to keep the light of the Weatherometer from penetrating readily to the bottom of the coating.

Absorption of Water: Free films nearly always absorbed more water during the 3-day soaking test than bound films on glass of the same paint and comparable thickness. The few exceptions to this rule were with paints of relatively low absorption, and the differences between the free and bound films were small. Although both faces of the free films were exposed to water, whereas water had access to 1 face only of the bound films, the period of exposure, 3 days, was so long in consideration of the thinness of films tested that it is very difficult to attribute the greater absorption by free films to the greater area of surface exposed. There was ample time for water to penetrate to the center of the thickest films. Moreover, the differences between free and bound films are as striking for the thinner films of each paint as they are for the thicker films. The more probable explanation, therefore, is that restraint of the bound films by their attachment to the glass substrate developed internal stresses of sufficient magnitude to reduce the absorption of water below the quantity taken up when the film was free to swell in all three directions.

Nevertheless, even bound films of some paints absorb surprisingly large quantities of water. The greatest absorption recorded was nearly 63 percent by volume for the unweathered thinner film of zinc oxide paint. The corresponding free film absorbed 90 percent. The smallest absorption by a bound film was 4.4 percent by the thicker unweathered film of white lead paint for which the corresponding absorption by the free film was 6.5 percent. Unweathered films of raw linseed oil absorbed 17.5 percent for the thicker and 10.3 percent for the thinner films when bound, compared with 21.8 percent for the thinner, and 10.8 percent for the thicker film when free.

Table 4.--Data for chips of naturally loosened paint from coatings on wood applied on a test fence at Madison, Wis., in 1936, maintained by periodic repainting with the last repainting in 1948, collected in 1952, and kept indoors until tested in 1954

Paint	Density	Film thickness T_o	Absorption of water A/V_o	Swelling in volume ΔV_s	Swelling efficiency $\Delta V_s V_o/A$	Redried: change in volume ΔV_r	Weight loss while soaking S_2/V_o
		Mils	Percent	Percent	Percent	Percent	Percent
Lead-zinc, LZ_{23}	2.80	17.5	23.7	21.0	89	+0.2	1.6
Lead-zinc, LZ_{37}	2.87	13.4	23.4	18.1	77	-1.5	2.2
Lead-zinc-inert, $(LZ_{30})_{80}$	2.74	10.3	26.5	21.3	80	-1.3	2.1
Lead-zinc-inert, $(LZ_{15})_{33}$	2.32	18.1	18.8	17.3	92	+.8	.4
Titanium-lead-zinc, $(TL_{28}Z_{28})_{116}$	2.67	9.3	29.9	26.9	90	-.7	1.6
Titanium-zinc, $(TZ_{23})_{107}$	2.33	11.3	45.2	41.4	91	+1.1	2.9
Titanium-zinc, $(TZ_{66})_{207}$(e)	2.20	10.0	30.6	26.6	87	-.8	1.7
Lithopone-lead-zinc, $(SL_{11}Z_{23})_{75}$	2.31	15.1	24.5	21.7	89	-.6	1.7

The absorptions by different kinds of paints and by thick and thin films of any one paint when in the bound condition ran parallel, at least qualitatively, to the corresponding absorptions by the free films. Thus, if one paint took up more water than another when bound, it did so also when free. Thin films always absorbed more water than thick films of the same paint whether the films were bound or free.

Artificial weathering increased the absorption of both bound and free films of unpigmented raw linseed oil and bodied linseed oil at comparable film thickness. White lead paint exhibited the same effect of weathering, but at a lower level of absorption. All of the other paints absorbed much less water after weathering than they did before. The first 7½ days of artificial weathering usually effected a greater change in absorption than the second 7½ days did; in fact, there was often a minimum of absorption after 7½ days of weathering and a slight increase again after 15 days.

Swelling in Water: The volumetric swelling, $\triangle V_s$, of all of the unweathered vehicles and paints in tables 1 and 3 paralleled and approximated reasonably closely the absorption of water. For unweathered, bound coatings, the swelling efficiencies were between 99 and 120 percent, and for free coatings between 92 and 107 percent. The exceptionally high and exceptionally low values were for films of very low absorption and swelling, for which the experimental errors were therefore greatest. All of the water absorbed by the unweathered films, therefore, resulted in swelling, presumably because there were no voids in the films that could

become filled with water without increase in film volume. The fact that the swelling efficiency often slightly exceeded 100 percent may be attributed for the present to underestimation of the absorption because of evaporation of absorbed water while the soaked films were being weighed in air; although the possibility that the volumetric swelling does at times actually exceed the volume of water absorbed will be considered in a subsequent publication in this series.

After weathering, the swelling efficiency of bound films was always less than 100 percent. For commercial paint No. 5, the efficiency dropped as low as 51 percent. A similar trend was evident for the free films, but it was not so marked, except for commercial paint No. 5, and it was not so consistent. Some of the water absorbed by weathered films often fails to cause swelling, presumably because voids have been developed within the weathered films that take up water without changing the volume. Apparently, bound films, which can swell or shrink in thickness only, reveal the porosity developed by weathering more fully than do the free films, which can swell and shrink in three dimensions. The approximate equality in density of bound and free films indicates that they are about equally porous before immersion in water for the soaking test; but when the wet films, plasticized by the absorbed water, dry out again afterward, the free films may be able to draw together and collapse the pores more nearly completely than the bound films can.

For free films, the volumetric swelling was distributed between areal swelling and swelling in thickness. The distribution, however, was not in fixed proportions. Thus, for the thin, unweathered film of magnesium silicate paint, the volumetric swelling was 56.1 percent, the areal swelling 15.9 percent, and the swelling in thickness 31.5 percent; whereas, for the thin, unweathered film of titanium-lead-zinc paint, the corresponding figures were 61.1, 38.0, and 15.6 percent, respectively. Such variations appear throughout table 3 not only among paints but between weathered and unweathered films of the same kind of paint. In the previous paper (3) it was shown that many films swell much more across than with the grain of the paint.

Recovery on Redrying: On redrying after the soaking test, both bound and free films usually shrank to a volume slightly less than their initial volume before soaking. The loss in volume may be attributed to the loss of soluble ingredients by leaching during the soaking period. Quantitative comparison of the volumetric shrinkage with the leaching loss is not possible in the absence of knowledge of the density of the soluble ingredients. Usually the leaching loss in grams per 100 cubic centimeters was slightly greater than the percent shrinkage in volume, which agrees with the presumption that the soluble ingredients had a density greater than 1.

One of the 60 bound films in table 1, and 10 of the 60 free films in table 3 retained a larger volume after redrying than the volume before soaking, although all of them experienced loss of soluble ingredients during the soaking. Of the 11 films that remained somewhat swollen after redrying, 9 were films that had been weathered, and all 11 of them were films that exhibited less than 100 percent swelling efficiency in the soaking test. Eight of the 11 films were of paints that contained zinc oxide and were more brittle and less distensible than the other paints. It may be concluded at least tentatively, therefore, that the residual swelling left after redrying indicates voids left within the films after evaporation of the water with which they had been filled while the films were wet.

Failure of free films to return on redrying to their initial dimensions before soaking was much more frequent in the measurements of area than in those of volume. Of the 60 free films in table 3, there were 28 for which the area, when redried, exceeded the area before soaking. Twenty-two of the 28 were among the 24 films of paints that contained zinc oxide. The paints of highest absorption and swelling on soaking appear to be the ones most likely to retain swollen area after redrying. The harder, less distensible paints of high absorption and swelling thus seem to shrink more readily in thickness than in area when they dry out again. The results agree with phenomena that have long been observed in the moisture blistering of paints. Formation of blisters necessarily involves an increase in area of film. After the wet condition passes and the blistered paints dry again, the more distensible kinds of paint often draw down to a surface so level that the blistered area can no longer be seen; whereas, the less distensible paints often leave a rumpled surface, a sort of "double-chin" effect that clearly reveals the blistered area. Similiarly, in normal weathering of paints when cracking and curling occur, it can often be seen that, if the curled paint could be rolled out flat again, the parts on either side of the crack would have to overlap.

Both in swelling and in redrying of free films, measurements of changes in area alone prove inadequate and may lead to conclusions at variance with the understanding obtainable when the volumetric changes are measured also. When both volumetric and areal changes are observed, significant information is revealed about the internal structure of the films and the nature of the stresses that must be set up within them.

Loss in Weight While Soaking: The loss in weight of paint films during the 3-day soaking period were discussed in the previous paper (3). The loss arises from leaching of water-soluble substances probably formed by decomposition of the paint oils, chiefly during the soaking period. They can be recovered from the soaking water by evaporation. They consist of organic matter, together with inorganic constituents if the paint contained pigments partly soluble in water or capable of forming soluble salts with organic acids. In this paper, it is sufficient to point out that bound films yielded solubility losses of the same order of magnitude as those from free films. Thick films lost less in proportion to their volume than did thin films of the same kind of paint, whether the films were bound or free.

Comparison of Artificial and Natural Weathering

Table 2 reports results with free films of 2 unpigmented oils, 11 laboratory-made paints, and 5 commercial paints when tested before weathering, after artificial weathering for 15 days, and after natural weathering for 6 months and for 12 months. The 6-month period of natural weathering was from May to October 1953, inclusive, which included the summer months; the 12-month period was the extension through April 1954, which included the winter season.

Weight Losses While Weathering: Losses in weight during weathering, either artificial or natural, were substantial. Paint T_{420}, in which anatase titanium dioxide was the sole pigment, lost 107 grams per 100 cubic centimeters of weathered film after 12 months of natural weathering. But much of the loss by paint T_{420} was pigment because it was chalking very freely by the end of the exposure period. Although other paints chalked observably, none of them was chalking freely enough to attribute much of their weight loss to erosion of pigment. For most paints, the losses are believed to consist chiefly of volatile organic products of oxidation and to leaching of soluble decomposition products of the paint oils and soluble metal salts of such products. Raw linseed oil lost 92 grams per 100 cubic centimeters of weathered film after 12 months' natural weathering; bodied linseed oil lost a little less than half as much. Paint TL_{40} and commercial paint No. 5, which was pigmented with titanium dioxide and extending pigments, lost somewhat more than bodied linseed oil but less than raw linseed oil. Magne-

sium silicate paint lost a little less than bodied linseed oil; and pure white lead paint, paint L, lost less than magnesium silicate paint. All paints that contained zinc oxide lost less than pure white lead paint, but the lowest loss after 12 months' natural weathering was 15.6 grams per 100 cubic centimeters of weathered film of paint $TL_{20}Z_{20}$. These findings agree with measurements of the rate loss of coating thickness in practical exposure tests (2).

In natural weathering, most of the loss in weight took place during the first 6 months. After 12 months, the losses were usually greater but only slightly so. This is strong evidence that the weight losses consist chiefly of leachings of soluble decomposition and reaction products, rather than mechanical attrition by chalking or erosion. Oxidation takes place most rapidly in young films and slows down as they get older. Erosion, on the other hand, is negligible in young films and speeds up as they age. To be sure, the first 6-month period of natural weathering included the summer period during which paint deterioration proceeds more rapidly than in winter, but the 6-month losses approach the 12-month losses too closely to be attributed largely to the difference between summer and winter seasons.

In artificial weathering for half a month, the weight losses were smaller, usually much smaller, than the losses in natural weathering. The shorter period of time for artificial weathering may be partly responsible for the difference, but another and perhaps more important factor is the brevity of the periods of exposure to water in artificial weathering. Each spraying with water, during which soluble ingredients could be leached out, lasted only a few minutes, after which the films had time to dry thoroughly before again reaching the sprays. The time was insufficient for the water to affect more than a thin, superficial layer of the paint films. Other workers (6) also have pointed out that customary cycles of artificial weathering fail to provide long enough periods of exposure to wet conditions.

In table 1, bound films of paints containing zinc oxide usually gained in weight during exposure to artificial weathering. Losses by other paints were usually much less than the losses for the same paints recorded in table 2. The gains by the zinc oxide paints were clearly abnormal and were traced to deposits from the hard water used in the Weatherometer sprays. The metal clips by which the test specimens were held in the Weatherometer drum became coated with the deposits. This source of error was corrected by equipping the Weatherometer with a tank and pump to supply distilled water to the sprays for the experiments recorded in table 2.

Absorption of Water: Weathered films of pigmented paints, except pure white lead paint, absorbed less water when soaked than the unweathered films of the same paints, whether the weathering was artificial or natural. On the whole, artificial and natural weathering did not differ greatly in their effects on absorption. If there was any real difference between them, after making reasonable allowances for differences in film thickness, the difference was that absorption by artificially weathered films was more often slightly less than slightly more than the absorption by similar naturally weathered films. At any rate, the results indicate that half a month of artificial weathering ages the films fully as much as a year of natural weathering, at 45° facing south, though it does not follow that the chemical and physical effects of the 2 methods of weathering are the same in all respects.

Swelling and Swelling Efficiency: No significant differences were observable in the effects of artificial and natural weathering on the swelling and swelling efficiency of paint films. Before weathering, the swelling efficiency was usually close to or slightly greather than 100 percent; and after weathering of either kind, the efficiency as a rule was slightly less, sometimes markedly less than 100 percent. Likewise, the distribution of the volumetric swelling between area and thickness changes was about the same for artificial and for natural weathering.

Shrinking on Redrying: When redried after soaking, all unweathered films returned to less than the volume before soaking, presumably because of leaching of soluble ingredients. After artificial weathering, films of 5 paints, chiefly paints that contained zinc oxide, retained after redrying slightly more than their initial volume. All films naturally weathered for 12 months returned after redrying to less than the initial volume; but of the films naturally weathered only 6 months, those of 10 paints had larger-than-initial volume after redrying. The residual swelling was small for 3 zinc-containing paints and pure white lead paint; but it was large, from 14.5 to 30.9 percent, for 6 paints, namely, paints Z, LZ_{37}, $TL_{20}Z_{20}$, $TL_{10}Z_{10}$, TZ_{20}, and commercial paint No. 3. Large residual swelling after redrying was usually associated with low swelling efficiency during soaking. The area of films of all zinc-containing paints, except commercial paint No. 4, was always larger after redrying than it was before soaking, even for unweathered films.

Thus, the behavior of zinc-containing paints on redrying after soaking suggests that their physical condition after 6 months of natural weathering is farther away from the unweathered condition than is the condition after 12 months of weathering. On the other hand, it has already been pointed out that the data for loss in weight while weathering suggest that the chemical composition changes greatly during the first 6 months, but not much more during the next 6 months. But it may be that the physical condition that determines the ability to shrink again after becoming swollen in water, oscillates beteween limits during weathering, or that it depends more on the weather conditions for a few days immediately before sampling than on the total time of exposure to weathering.

Solubility While Soaking: Artificially weathered films lost less weight from leaching of soluble ingredients during soaking than the corresponding unweathered films did, except for the pure zinc oxide paint and commercial paint No. 5. Naturally weathered films of bodied linseed oil, all zinc-free paints, and commercial paints Nos. 1, 2, and 3 also lost less soluble material than the corresponding unweathered films. But naturally weathered films of raw linseed oil, all laboratory-made paints that contained zinc oxide, and commercial paint No. 4 had more soluble material than the corresponding unweathered films. (The laboratory-made paints were made with raw linseed oil, but the commercial paints contained substantial proportions of bodied drying oils.) Solubility was higher in naturally weathered than in artificially weathered films of all paints for which the data are available for such comparison, except pure zinc oxide paint and commercial paint No. 5.

It appears, then, that artificial weathering tends to reduce solubility below that of unweathered films. Natural weathering, on the other hand, seems to increase the solubility of films of raw linseed oil and of paints containing zinc oxide unless they also contain much bodied oil. For bodied linseed oil and zinc-free paints, the solubility after natural weathering, though less than that of unweathered films, is not so low as it is in artificially weathered films. More should be known about the chemistry of paint weathering before an explanation is offered for these facts.

Chips of 16-Year-Old Paint

An opportunity to measure the volumetric swelling of some very old paint films was afforded by a test-fence study of paint maintenance programs started at Madison, Wis., in 1936, the results of which have been published (2). The paint coatings were renewed by repainting at intervals, always with the same kind of paint, until 1948. After that, they were all allowed to stand without

further repainting until 1952 to provide a period for observing the outcome critically. The thicker coatings of many of the paints were then scaling badly enough to permit collection of samples of free films large enough to test for absorption of water and volumetric swelling. The chips were collected in the spring of 1952 and kept indoors until the measurements were made in January 1954.

The results are reported in table 4. All of the paint chips available for study were more than 9 mils thick, one of them 18.1 mils thick. The absorption and swelling measured, then, are for films of excessive thickness and presumably are much lower than the absorption and swelling of similar films of normal thickness, say 5 mils. All chips available were of paints that contained zinc oxide and that were therefore high in absorption and swelling. Zinc-free paints, even in excessively thick films, did not loosen and scale in pieces large enough to afford samples suitable for measurement.

The absorption of water ranged from 18.8 percent for paint $(LZ_{15})_{33}$ to 45.2 percent for paint $(TZ_{23})_{107}$. Absorption by the 2 paints in which there was no white lead was greater than the absorption by any of the 6 paints in which there was white lead. Although the absorptions were lower than for comparable paints in table 2 that received natural weathering for 1 year, the differences were no greater than might be accounted for by the much greater thickness of the 16-year-old films. Thus, it appears that most of the reduction in absorption caused by weathering of paint films occurs in the first year, or perhaps even in the first 6 months.

Volumetric swelling of the 16-year-old films was always less than the absorption of water, and the swelling efficiency was therefore less than 100 percent. The efficiencies ranged from 77 to 92 percent. The 16-year-old paints did not differ greatly from 1-year-old paints in swelling efficiency. Moreover, the shrinkage of the swollen films on redrying and the loss of soluble ingredients during the 3-day soaking period were about the same for the 16-year-old as for the 1-year-old films.

Conclusions

1. A technique was developed for measuring the volumetric swelling both of free films and of coatings of house paints bound on glass when soaked in distilled water for 3 days, and the shrinkage of the free and bound films when dried again after soaking. The volumetric measurements in conjunction with measurement of the absorption of water, the changes in area, and the loss of soluble ingredients by leaching previously reported add materially to the understanding of the action of water on house paints of different kinds. Paints were tested before exposure to weathering and after exposure to artificial and to natural weathering.

2. Bound films absorbed somewhat less water and swelled correspondingly less than free films, although the absorption and swelling of bound films of some paints were surprisingly large. The bound films, which could swell in thickness only, were perhaps unable to adjust their volume to the full extent of swelling and remained under greater internal stresses than the free films. Free films changed in length, width, and thickness.

3. Thick films, whether bound or free, absorbed less water and swelled less than otherwise similar thin films.

4. Unweathered films, either bound or free, usually swelled at least 1 cubic centimeter in volume for each gram of water absorbed. Artificial weathering in a Weatherometer reduced the absorption and swelling. Weathered films tended to swell less, sometimes much less than 1 cubic centimeter for each gram of water absorbed. It may be that the weathered films become porous and are able to hold some free water that causes no swelling in addition to the swelling water.

5. When redried after soaking, most films shrank to a somewhat smaller volume than they had before soaking. The loss in volume is attributed to loss of soluble ingredients by leaching during the soaking. Practically all films suffered loss in weight from this source. But a few films, chiefly of highly absorptive paints in which there was zinc oxide, were slightly greater in volume after redrying despite loss of soluble ingredients. This seems to be further evidence of the development of voids within some films.

6. All films lost weight substantially during either artificial or natural weathering. The losses were much larger in natural than in artificial weathering. In natural weathering, the major portion of the loss took place during the first 6 months. The loss in weight is attributed chiefly to leaching of soluble ingredients, rather than to mechanical erosion or chalking, because few paints were chalking very freely within the first 6 months of natural weathering.

7. In artificial weathering, the use of hard water in the Weatherometer sprays led to low measurements of weight loss; in fact, some paints that contained zinc oxide actually gained in weight. Evidently, there were gains in weight from deposition of the salts present in the hard water, which partly or wholly overbalanced the losses of soluble ingredients from the paint films. Such abnormal results were corrected by supplying distilled water to the Weatherometer sprays.

8. Absorption and swelling of films were reduced fully as much by 15 days of artificial weathering as by 12 months of natural weathering.

9. Chips of paint films from a test-fence study of paint-maintenance programs were available for examination. The paints had been maintained by repainting homogeneously at intervals throughout the period from 1936 to 1952, with the last repainting in 1948. The absorption and swelling of the 16-year-old paint chips, when reasonable allowance was made for their excessive thicknesses, was comparable with the absorption and swelling of similar paints when weathered for only 1 year. It seems, then, that the reduction in absorption and swelling of paint films caused by weathering takes place during the first few months and thereafter remains nearly constant for at least the next 15 years.

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Slope of Grain in Engineered Wood[1]

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Slope of grain, influencing physical and mechanical properties, should be recognized and designed-for in efficient utilization of wood. Increasing importance of laminating calls for more intensive research in this subject relative to product strength and stiffness. Efficient methods of production and inspection of boards to minimize grain limitations merits attention.

WOOD IS ONE OF THE OLDEST materials used by man in the construction of home, business and place of worship. Yet, its use as an engineered material is a very young science. It has been only in the last thirty or so years, that the physical, chemical and mechanical properties of wood have been sufficiently studied to furnish a basis for the use of wood as an engineered material. Because of wood's heterogeneous structure the determination of its basic properties has been complex. When it is considered that most of the strength as well as physical properties, such as sound transmission and heat conductivity, vary with the longitudinal, tangential and radial direction of each piece of wood it is understandable why the development of basic data on wood has but recently been studied in any degree.

One of the most important single characteristics in a board is its slope of grain. This feature of a wood member influences practically all of its physical and mechanical properties.

Some confusion exists in the forest products industries about the exact meaning of slope of grain. Quite frequently the word grain is used to describe the surface appearance of the wood. This discussion limits itself to the slope of grain which occurs when the fibers do not run parallel to the main axis of a board. In industry, slope of grain is often referred to as cross grain.

A spiral alignment of the longitudinal elements in the trunk of a living tree produces what is properly known as spiral grain. When this spiral grain reverses at intervals a condition of interlocking grain results. Perhaps the best illustration of a wood that has interlocking grain is red gum. This interlocking grain in red gum railroad cross ties is a definite asset and results in exceptionally good resistance to wear. Diagonal grain usually occurs because of the common method of through and through sawing practiced in the majority of sawmills. The amount of diagonal grain depends to a large measure on the taper of the log at the time it is sawn. The greater the taper the more diagonal grain. To achieve a maximum utilization of material in a log modern methods of sawing will continue to be such that boards of various amounts of diagonal grain will be produced. Slope of grain or cross grain on the radial surface of a board is usually referred to as diagonal grain; that on the tangential surface as spiral grain.

Cross grain is usually expressed as a slope. This slope is expressed between a fiber alignment in the board and the long axis of the piece. Thus, if the grain deviates one inch from the long axis of the piece over a distance of 12 inches the slope of one inch in 12 is in evidence. In the event that two slopes are evident on two adjacent faces the following formula is usually used:

$$\frac{1}{x} = \sqrt{\frac{(1)^2}{(a)} + \frac{(1)^2}{(b)}}$$

in which x refers to combined slope and a and b to the slope on each of the two adjacent faces.

Methods of Measuring Slope of Grain

The measurement of slope of grain in wood can be accomplished by a number of different methods. The one most commonly used in production is running a scribe with a sharp point over the surface of the wood and the point, which is free to swivel, follows the vertical fibers. Measurement of the deviation of the resulting line from a parallel edge of the board over a given length produces a measure of a slope of grain.

Other methods used are free flowing ink to define the direction of the longitudinal fibers, observation of resin ducts, large pores and the direction of seasoning checks. Specialized pieces of equipment have been developed to measure slope of grain such as a plate of clear glass, with etched lines corresponding to slopes of grain on the glass; the plate is laid over the board in such a way that the slope of grain can be read directly off the graduations on the glass. Parallel bars, dividers or calipers have also been used for this purpose. However, in all cases the slope of grain must be determined board by board. In actual production this is quite a task. The current 3 billion dollar wood ship building program is based on the structural use of wood with definite slope of grain limitations. Procedures for inspection of the lumber used in the production of these laminated and solid members is a difficult problem. One of the outstanding pieces of production equipment on which some data needs to be developed is a device which will automatically select lumber of a given slope of grain on a go or no go basis, in other words, if the slope of grain of 1 in 15 is required, all boards with a slope of grain steeper than 1 in 15 would be discarded by this automatic device.

Slope of Grain in Relation to Physical Properties of Wood

The slope of grain in a piece of wood affects most of its physical properties. Some of this influence of slope of grain has been studied in detail; much of it needs a considerable amount of additional research.

The relationship of direction of grain in wood to its reaction to heat has been studied in some detail. The coefficient of linear thermal expansion of wood varies with the species and grain direction. For Douglas fir, for example, the coefficient parallel to the grain is 3.16×10^{-6} while perpendicular to the grain in the tangential direction the coefficient is 42.7×10^{-6} and in the radial direction 27.9×10^{-6}. The foregoing differences are of great importance in many industrial applications of wood. For example, in the gluing of wood to metal, thermal expansion is a primary problem; the same is true in the production of composite plastic and wood members.

When wood is considered as an insulating material its thermal conductivity characteristics become important. While only a limited amount of information is available on the subject it has been found that the thermal con-

[1] Presented April 29, 1954, at Northeast Section meeting of FPRS at Williamsport, Penna.

ductivity along the grain is 2¼ to 2¾ times that across the grain. While the research work done on the subject has been excellent much additional work is required in this field.

The sound transmitting characteristics of wood are also affected by the direction of grain in the wood. For example, the speed of sound in ft./second in ash is 15,310 parallel to grain and about 4,350 perpendicular to the grain. The sound characteristics of wood are extremely important in the development of a non-destructive method of testing wood members. Through the use of a dynamic-resonance method, the modulus of elasticity of wood can be determined without any harm to the wood. While this extremely important development of testing is in its infancy it promises to eventually permit the inspection of structural wood members for strength and stiffness. Influence of slope of grain will be one of the factors that will be evaluated. There are already indications that this influence is measurable by dynamic means.

Dimensional Change and Slope of Grain

The grain deviations in a piece of wood influence the dimensional changes resulting from variations in moisture content. Cross grain in wood is responsible for warpage of lumber which occurs during seasoning. Wood with interlocking grain is difficult to dry without warping and requires special attention in seasoning to achieve a uniformly good product.

The differential in shrinkage and swelling properties of wood parallel and perpendicular to grain is recognized in the production of plywood and similar products which are designed to give the maximum amount of dimensional stability. The principle of cross lamination, however, should be used with caution. Gluing of pieces of wood over ¼ inch in thickness in a cross ply construction can be dangerous because of the high stresses which are set up in the glue lines.

Effect of Slope of Grain on Mechanical Properties

More is known about the influence of slope of grain on the mechanical properties of wood than on any of its other physical properties. All of us are familiar with what excessive cross grain will produce in a ladder rail or hammer handle. Unfortunately there have been some rather serious accidents resulting from lack of attention and understanding of the significant reduction in strength of a member which has excessive slope of grain. Equally unfortunate have been certain isolated instances of imposing excessively severe limitations on the slope of grain permitted in structural members. Over-specification of this nature unnecessarily limits the amount of available material and further increases the cost of manufacture.

Numerous publications are available in which the precise relationship between slope of grain and the different strength properties are presented. For each species of wood every strength property such as modulus of rupture and impact bending strength are affected to a different degree by a given slope of grain. For example, a slope of grain of 1 in 10 inches in Douglas fir would reduce the modulus of rupture of clear wood by about 25 percent; the impact bending strength would be reduced approximately 65 percent for the same slope of grain.

The limitations on slope of grain in structural members are based on the service requirements of the members. In aircraft parts, slopes steeper than 1 in 15 were not usually used. High strength laminated parts used in naval construction have slope of grain limitations as steep as 1 in 18. Structural members used in industrial construction range from 1 in 8 to 1 in 18.

In the production of laminated members end joining is usually necessary to produce the required length in the individual laminations. Usually scarf joints are used and the slope of scarf is dictated by the strength efficiency that is required. In design of laminated wood members in which the slope of grain is limited to 1 in 20 the effectiveness of a 1 in 12 sloped scarf would be approximately 90 percent of the strength of the adjoining uncut portion; the effectiveness of a 1 in 8 scarf would be 80 percent. If the slope of grain of the wood is specified to be 1 in 14, however, the foregoing effectiveness would no longer be valid. With a slope of grain of 1 in 14 in the wood the effectiveness of a 1 in 12 scarf cut across the grain would in reality only be equivalent to the effectiveness of somewhat less than 1 in 10 because of the added proportion of end grain appearing in the scarf surface. As the amount of end grain in a glue joint increases the efficiency of the joint decreases. The steeper the slope of grain in the wood the more end grain is involved in the gluing of a scarf of given slope. Of course, if the slope of the scarf followed the slope of grain in the wood the foregoing combined effect would be minimized. In actual production it would be necessary to assume that some of the scarf would have to be cut against the slope of grain in the wood hence it is necessary to use the weakest possible combination as the limiting factor in design.

All of the preceding discussion applied to the portion of members which was stressed in tension. Scarfs with a slope of 1 in 5 or flatter have no effect on the working stress used in compression. The relationship for end joints other than plain scarfs with slope of grain in the member has not been as thoroughly studied and considerable additional research is necessary.

In design problems where compressive forces act at an angle to the grain it has been found that through the use of the Hankinson formula a close approximation of the working stress that can be used in the members loaded in compression, can be computed. This formula is usually written

$$N = \frac{PQ}{P \sin^2 \theta + Q \cos^2 \theta}$$

in which:

P = stress in compression parallel to grain

Q = stress perpendicular to grain

θ = angle between line of action of the force and direction of grain in the wood.

Some years ago the writer was fortunate in having the opportunity of working on a problem in which the effect of slope of grain on modulus of elasticity was studied. By using the modulus of elasticity parallel to the grain and the modulus perpendicular to the grain it was possible to show that Hankinson's formula is applicable to stiffness in beams as well as stress in compression. This was proven by actual test data.

In the steam bending of wood to achieve the desired contour of the finished part, close attention to the slope of grain in the piece is necessary. For bent boat members a slope of grain of 1 in 15 is specified. A recent development program performed for the Navy revealed that in the steam bending of laminated members a slope of grain as steep as 1 in 6 can be incorporated in the inner laminations or core of the members without sacrificing the steam bending properties of the member.

Summary

The slope of grain in wood is an inherent characteristic which must be recognized and designed for in the efficient utilization of wood. The majority of the physical properties are affected by changes in grain direction. Probably of greatest importance is the influence slope of grain has on the mechanical properties of wood.

More information should be obtained on the relationship between slope of grain and other properties of wood; this is a fertile field for both basic and applied research.

The increasing importance of laminating as a method of developing new markets and improving utilization of lumber necessitates more intensive research on the influence that slope of grain in the individual laminations has on the total strength and stiffness of the whole member. Efficient methods of production and inspection of individual boards for slope of grain limitations merits considerable attention.

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Analysis of Methods for Determining the Coefficient of Moisture Diffusion in Wood[1]

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The relationships of the coefficient of internal moisture diffusion D and of the surface emission coefficient S to each other, and to the moisture gradients that occur in wood during the seasoning process, are cited. The moisture diffusion coefficient D for wood appears in three general forms whose interrelationships are derived. A number of steady-state and unsteady-state methods for finding the diffusion coefficient are analyzed with respect to their relative merit. Some of these methods have not been applied to wood. Particular attention is given to the use and limitations of the unsteady-state diffusion equations.

THERE IS CONSIDERABLE interest in the wood industry in methods of improving processes for seasoning wood. Continued improvement can be accelerated by the accumulation of a larger body of knowledge concerning the effect of various factors such as wood structure, moisture content, and temperature on the rate at which moisture moves through wood and on the magnitude of the moisture gradients which exist in wood during the drying process. The most convenient way to describe quantitatively the effect of these various factors is in terms of their influence on the moisture diffusion coefficient of wood.

The coefficient of moisture diffusion in wood determines the rate of internal moisture movement in relation to the existing moisture gradient. Another coefficient which is important in relation to wood seasoning is the coefficient of surface moisture emission which determines the rate at which moisture is emitted from the surface of drying wood. The interrelationship of the coefficients of internal moisture diffusion and of surface moisture emission, together with the thickness of the drying stock, governs the rate of drying as well as the steepness of the moisture gradients that exist at various points in the wood interior during different stages of drying. The steepness of the moisture gradients is, of course, one of the decisive factors which affects drying stresses.

During the drying of thin wood veneers the drying rate is controlled by the coefficient of surface emission, as Fleischer (8) has shown, and the coefficient of internal diffusion is relatively unimportant. However, for thicker material the internal diffusion coefficient becomes important and may control the rate of drying, particularly when air velocities are high enough to reduce the resistance to moisture emission at the surface to a comparatively low value. In the intermediate thicknesses, particularly where the air velocity is low, both the coefficient of surface emission and the coefficient of internal diffusion are important. This paper is primarily concerned with the coefficient of internal moisture diffusion in wood (sometimes referred to as the "K-factor"). It is specifically proposed to interrelate the three basic forms in which the moisture diffusion coefficient appears, to analyze the methods by which it has been obtained in one or more of these forms by various workers, and to suggest new methods for measuring the diffusion coefficient for wood. It is also proposed to relate the coefficients of internal diffusion and of surface emission to each other and to describe a method whereby both of these coefficients can be obtained simultaneously.

The coefficient of moisture diffusion can be obtained in any of its three basic forms from studies of the rates of moisture movement through wood under steady-state conditions or under unsteady-state conditions. The relationship between the different forms of the diffusion coefficient is defined basically in terms of steady-state moisture movement, however, and therefore this will be considered first.

Steady-state Moisture Movement in Wood

If the two opposite faces of a board are subjected to different but constant atmospheric conditions such that the equilibrium moisture content at each face is different, a condition of equilibrium is eventually attained in which the rate of moisture movement through the board from the high to the low moisture content side is constant. Under these conditions the moisture content at any point in the board also remains constant. If the flow is confined to a direction perpendicular to the faces

[1] A 1954 "Wood and Wood Products" Graduate Award entry written while author was a student at Yale University. The Award is sponsored by Vance Publishing Co., Chicago.

of the board,[1] a moisture distribution is attained in the board whose shape depends upon the variation of the diffusion coefficient with moisture content. Furthermore the moisture distribution for a given board may be expressed in at least three different systems of units. In the first of these, the moisture distribution is given in terms of moisture content percent M, defined as grams of water per gram of oven-dry wood, multiplied by 100.[2] In the second system of units, moisture distribution is given in terms of the variation in equilibrium vapor pressure h at various points in the wood, expressed in centimeters of mercury. In the third system, the moisture distribution is given in terms of the variation of the moisture concentration C, which is defined as grams of water per cubic centimeter of wood.

Basic Forms of the Moisture Diffusion Coefficient: The rate of flow of moisture through wood under steady-state conditions is not only constant with time but also with respect to distance x, measured perpendicular to the face of the specimen, even when the moisture distribution is not linear. The rate of flow of moisture per unit area, called the flux of moisture, is numerically equal to the product of the coefficient of diffusion and the moisture gradient in the direction of movement at any point x. The defining equation, which is identical with the steady-state form of Fick's law (1), is

$$F = (1/A)(dq/dt) = -DdC/dx \quad \text{----------(1)}$$

where the flux F of moisture is the rate of flow of moisture q (grams) per unit time t (seconds) per unit area A (cm^2), D is the diffusion coefficient and dC/dx is the moisture concentration gradient, in grams of moisture per cubic centimeter of wood per centimeter, at the point x. This form of the diffusion coefficient D, defined by equation 1, is the most useful of the three forms since it is identically equal to the form which arises directly from the unsteady-state diffusion equation. It has units of square centimeters per second when A, q, t, C, and x have the units given above.

The relationship of the basic form D of the diffusion coefficient to the other two forms which have been used for wood is easily derived since they differ from D only in the definition of the gradient if the units of the flux F are the same. Equation 1 is then modified to read

$$F = -D_m(dM/dx) \quad \text{----------(2)}$$

or, alternatively

$$F = -D_h(dh/dx) \quad \text{----------(3)}$$

where D_m is the form of the diffusion coefficient based on a moisture content gradient dM/dx, and D_h is the coefficient based on a vapor pressure gradient, dh/dx. The units of D_m are grams of water per second per centimeter per percent moisture content. Those of D_h are grams of water per second per centimeter per unit of vapor pressure.

The relationship of D to D_m is easily obtained from equations 1 and 2 if the flux F has the same units in each case, and

$$D = (dM/dC)D_m \quad \text{----------(4)},$$

or

$$D = (100/G)D_m \quad \text{----------(5)},$$

since $C = MG/100$, where G is defined as the oven-dry weight of the wood, in grams, divided by its swollen volume, in cubic centimeters, at the moisture content M. It is clear therefore that G has the same numerical value as the specific gravity of the wood at the moisture content M, as defined in the United States, although it has the dimensions of density (grams/cc).

Equations 2 and 3 show that D_m and D_h are related by

$$D_m = (dh/dM)D_h \quad \text{----------(6)},$$

or

$$D_m = h_o(d(h/h_o)/dM)D_h \quad \text{---(7)},$$

and, combining equations 5 and 7

$$D = (100h_o/G)(d(h/h_o)/dM)D_h \quad \text{----------(8)},$$

where h_o is the saturated water vapor pressure of the air at the temperature at which the diffusion is taking place, and $d(h/h_o)/dM$ is the slope of the relative vapor pressure vs. moisture content curve for the wood under consideration at the moisture content M. This slope, which varies with both moisture content and temperature, has been plotted in Figure 1 from the hygroscopic isotherms for spruce as given by Stamm (19). The peak in $d(h/h_o)/dM$ which occurs at a moisture content in the region between four and eight percent corresponds to the inflection points of the hygroscopic isotherms.

The moisture diffusion coefficients for wood appear in all three forms in the literature, but for purposes of analysis in this paper all of them have been reduced to the form of D. It is convenient therefore to express the quantity of moisture in the wood in terms of moisture concentration C rather than in percent moisture content M, although the same principles apply in either case.

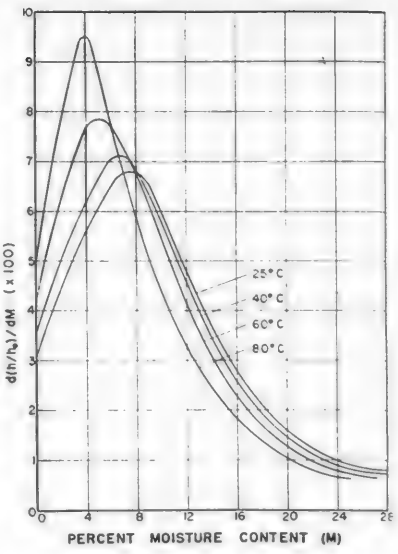

Figure 1.—Slope of the relative vapor pressure vs. moisture content isotherms, $d(h/h_o)/dM$, for spruce as a function of moisture content M at various temperatures (adapted from data of Stamm (19)).

Experimental Steady-state Methods for Measuring the Diffusion Coefficient: A number of experimental methods have been used to measure the diffusion coefficient for wood in one or another of its three basic forms. The techniques described below can be applied to determine any of the three forms directly merely by using the appropriate system for measuring the moisture gradient.

Some of the experimental techniques give an apparent or average value $\bar{D}$ for the coefficient, rather than the true coefficient D For example, consider the steady-state moisture distribution curve shown in Figure 2. There is no way of actually measuring this moisture distribution in the wood accurately without sectioning the specimen. Therefore, it is often assumed as a first approximation that the distribution is linear as is shown by the broken line in Figure 2, which intersects the moisture concentrations C_o and C_a, respectively, at the two faces of the board. It is assumed, furthermore, that the surface concentrations C_o and C_a are equal to the equilibrium moisture concentrations of the respective atmospheres adjacent to the board, which can be measured.[3] With these assumptions, and with knowledge of the moisture flux F, the apparent coefficient D can be obtained by substituting in equation 1 written in the form,

[1] For simplicity it is assumed throughout the paper that moisture movement is confined to the direction perpendicular to the faces of the board. This situation would prevail in reality only in a board of infinite width, but can be accomplished experimentally by sealing the edges and ends of a test specimen in order to prevent moisture gradients in any direction parallel to the faces. If this is not done the mathematical treatment becomes much more difficult without adding to a conceptive understanding of the problem.

[2] Centimeter-gram-second units will be used throughout in this paper.

[3] The assumption that the surfaces of the board have exactly the same concentration as the equilibrium concentration of the adjacent air is obviously untrue, since there would then be no movement of moisture from the board to the air or vice versa. However, provision of good air circulation makes the assumption reasonably fair if the moisture flux F is not too high, and if the surface temperature is equal to the air temperature.

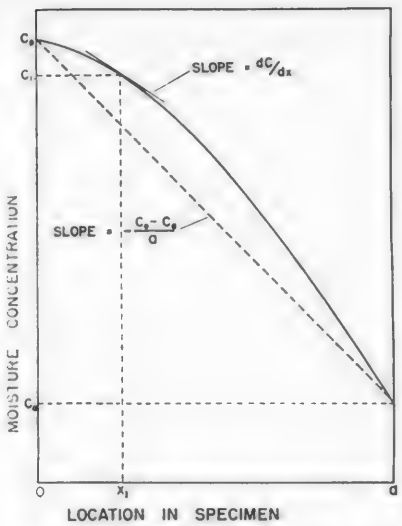

Figure 2.—Hypothetical steady-state moisture distribution for wood from x = O to *a* along the axis of moisture movement for the case where the diffusion coefficient D increases with increasing moisture concentration C. The mean secant slope of the curve between the concentrations C_o and C_a at the surfaces is shown by the broken line connecting C_o and C_a. The true slope dC/dx is shown for the location x_1, where the moisture concentration is C_1.

$\overline{D} = Fa/(C_o - C_a)$ ---------(9),
where the negative of $(C_o - C_a)/a$ is taken as the gradient in place of dC/dx.

If the steady-state moisture distribution is truly linear as has been assumed in calculating $\overline{D}$, then $\overline{D}$ is identically equal to the true coefficient D provided that C_o and C_a are the actual surface moisture concentrations. This linear relationship can occur only if the true diffusion coefficient D is independent of moisture concentration C over the range from C_o to C_a. In general the coefficient is dependent on C in which case the distribution is nonlinear, and must be ascertained by sectioning the test specimen in order to determine D at various points by direct use of equation 1. Suppose, for example, that the moisture distribution follows the pattern shown in Figure 2, as Martley (12) found in his studies on Scots pine. The diffusion coefficient at any point in the specimen, say at $x = x_1$, is given by equation 1, written in the form

$D = -F/(dC/dx)$ ---------(10)
where the gradient dC/dx is the slope of the moisture distribution curve at the point x_1. The coefficient D, thus obtained, is the true diffusion coefficient at the moisture concentration C_1, which is the moisture concentration at the point x_1. In a similar manner D can be determined at any moisture concentration between the limits of C_o and C_a, and the behavior of D as a function of moisture concentration C can be determined if the moisture distribution is known.

A major objection to the method of Martley described in the preceding paragraph, is that the specimen must be destroyed after a given test and cannot be used for repeated tests in which the effect of some other variable such as temperature can be determined on the same specimen. This objection can be overcome by the use of a modified steady-state method such as was used by King (10) to determine the true diffusion coefficient D for horn keratin. It has not been used on wood to the author's knowledge. King's method involves the measurement of the change in the steady-state flux F when the equilibrium moisture concentration on one side of the specimen is varied while that on the other side is kept constant. For example if C_o is varied while C_a is kept constant then the steady-state rate of flow can be shown to be a function of C_a as shown in equation 13 below. Equation 1 can be written

$F\,dx = -DdC$ ----------(11),
which can be integrated with respect to x between the limits of o to *a* for the left-hand term and with respect to C between the limits of C_o and C_a for the right-hand term, resulting in

$$Fa = -\int_{C_o}^{C_a} DdC \text{ ---------(12).}$$

The integral in the right hand term of equation 12 cannot in general be evaluated, since D is an unknown function of C. However, if the derivative of both sides is taken with respect to C_o, with C_a kept constant, the result in rearranged form is

$D = a(\partial F/\partial C_o)$ ----------(13),
which gives the true coefficient D at the moisture concentration C_o. Note that if D is constant with concentration C_o, that $\partial F/\partial C_o$ is constant for all values of C_o.

Joy (9) has used a graphical method for measuring the vapor-pressure form D_h of the diffusion coefficient as a function of relative humidity. The method next described is based on Joy's method. The experimental procedure consists, as in King's method, of measuring the apparent coefficient $\overline{D}$ for a number of tests on the same specimen in which the equilibrium moisture concentration on one surface of the specimen, say C_a, is maintained constant for each test but C_o is varied. A curve is then plotted of the apparent coefficient $\overline{D}$ against C_o for the constant value of C_a. The intersection of the curve of constant C_a with the extension of the C_o abscissa which has the same value as C_a, determines a point which fixes the location of the true coefficient D at the moisture concentration C_o which corresponds to it. If this procedure is repeated for a number of constant values of C_a, as is shown in Figure 3, the curve (shown as a broken line in Figure 3) which connects the intercepts of the curves of constant C_a with the corresponding vertical lines of constant C_o represents the variation of the true diffusion coefficient D with moisture concentration C in the wood. Joy's method requires more tests to obtain the same information that can be obtained from King's method with fewer tests. They both have the advantage compared with Martley's method that the same specimen can be used repeatedly, but the latter method can be used to show the variation in the true diffusion coefficient over the whole range of moisture concentrations from C_o to C_a in a single test. Martley's method, however, is unsuitable for use with thin specimens because of the practical difficulties of cutting accurately spaced thin sections from such test specimens and of making precise moisture determinations on the sections.

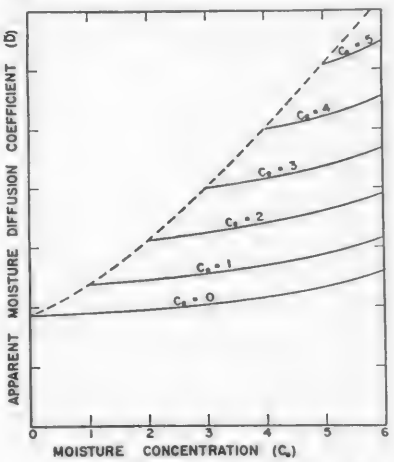

Figure 3.—Family of curves showing the apparent diffusion coefficient D as a function of moisture concentration C_o (expressed in arbitrary units) at one surface of the specimen. Each curve signifies a different constant moisture concentration C_a at the opposite surface. The curve shown as a broken line represents the true value of the diffusion coefficient at each moisture concentration C_o.

Unsteady-state Moisture Diffusion in Wood

The determination of the diffusion coefficient D from steady-state measurements has the practical disadvantage that considerable time is sometimes required before steady-state conditions are attained in a specimen. This handicap can be overcome by using unsteady-state methods for measuring D since these methods can be applied during the period before the steady-state condition is reached. Furthermore, the unsteady-state diffusion equations give a direct relationship of the diffusion coefficient to the drying times for wood and to the moisture gradients which arise during the drying process. The main disadvantages of the use of un-

steady-state diffusion equations, however, are their mathematical complexity and the necessity for making certain simplifying assumptions which are not always in agreement with the physical situation, particularly with respect to wood. For example, the assumption is usually made in applying the unsteady-state diffusion equation that the coefficient D is constant with moisture content, which is certainly not always true for wood.

Unsteady-state Diffusion with Constant Coefficient: The unsteady-state differential equation of moisture diffusion can be derived from any of the steady-state equations 1, 2, or 3 by considering the theoretical rate at which moisture is depleted from a thin layer of wood from any point in the interior of a drying board. For example, the rate of change of moisture concentration $\partial C/\partial t$ in such a thin layer is proportional to the difference in the rate at which moisture enters the layer from the wet interior of the board and the rate at which it leaves toward the drier exterior of the board. Such consideration leads to the unsteady-state diffusion equation (Fick's Second Law),

$$\partial C/\partial t = D\partial^2 C/\partial x^2 \quad \text{--------(14)}$$

for the case where D is assumed to be constant.

The most general solution of equation 14 is given by Newman (13) who has solved this equation subject to the boundary conditions that the original moisture distribution in the drying material is not necessarily uniform but is of some arbitrary form which is known. In this paper only the case of uniform original moisture distribution is considered for the sake of brevity. The other important boundary condition which Newman postulated is that the rate at which moisture is emitted from the surface of a drying material at any particular time is equal to the rate at which the moisture diffuses to the surface from the interior. In order to state this mathematically, Newman defined a coefficient which he called the coefficient of surface emission. This coefficient S, in terms of moisture concentration C, is defined as follows:

$$S = F/(C_a - C_e) \quad \text{---------(15)},$$

where S is the coefficient of surface emission (grams per square centimeter per second per unit difference in moisture concentration), F is the moisture flux or rate of flow of moisture q per unit area A per unit time t, and C_a and C_e are the moisture concentrations at the surface of the drying material and at equilibrium with the drying air, respectively.

For convenience, Newman defined the term H as the ratio of the surface emission coefficient S to the internal diffusion coefficient D, or $H = S/D$. Using this definition of H and the boundary conditions given above, Newman found, as the solution to the unsteady-state diffusion equation, in terms of E, the fraction of evaporable water remaining in the drying material at any point x, for a material of thickness $2a$, drying from both surfaces, that

$$E = (C - C_e)/(C_i - C_e) = \sum_{n=1}^{\infty} 2\Sigma(\sin \sigma_n/(\sigma_n + \sin \sigma_n \cos \sigma_n)) (\cos \sigma_n x/2a) e^{-(\sigma_n/2a)^2 Dt} \quad \text{---(16)}$$

where C is the moisture concentration at any point x in the drying material at time t; C_i and C_e are the initial and final uniform moisture concentrations of the material at all points; e is the base for natural logarithms; x is the location in the board with limits from $x = \pm a$ at the drying surfaces to $x = 0$ at the center of the board; n is any integer from 1 to ∞; and σ_n is a constant, defined by the relation,

$$Ha = \sigma_n/\cot \sigma_n \quad \text{----------(17)}.$$

Equation 16 gives the expected variation of E at any point x and time t for a drying material with constant coefficients D and S (hence for constant H).

Equation 16 can be transformed into a more useful form where the variation of the *average* fraction of evaporable water $\bar{E}$[4], remaining in the material can be predicted for various times t. This is accomplished by integrating equation 16 between the limits from $x = +a$ to $x = -a$, resulting in

$$\bar{E} = \sum_{n=1}^{\infty} 2\Sigma(\sin^2 \sigma_n/\sigma_n(\sigma_n + \sin \sigma_n \cos \sigma_n)) e^{-(\sigma_n/2a)^2 Dt} \quad \text{-----(18)}$$

Newman has calculated $\bar{E}$ as a function of Dt/a^2 from equation 18 for various values of the product Ha. These calculations are tedious and the writer has taken Newman's values, plotted them on semi-log paper, and by graphical interpolation has obtained curves for other values of Ha in addition to those given by Newman. Figure 4 shows the curves plotted from Newman's original data as solid lines while the interpolated curves are drawn with broken lines.

The curve for $Ha = \infty$ in Figure 4, corresponds to the solution to the diffusion equation which has been most often applied for the determination of the diffusivity coefficient D for wood. Assuming that $Ha = \infty$ is the same as assuming that $H = \infty$, since a, the half-thickness of the drying board is finite. If $H = \infty$, then S must be presumed to be infinite, since $H = S/D$ and D is not zero. This is identical with the assumption that the value of E at the surface immediately drops to zero when drying begins, which is the assumption that must be made in order to obtain the solution to the diffusion equation as given by Tuttle (20), Sherwood (18), and others, that

$$\bar{E} = (8/\pi^2) \sum_{n=1}^{\infty} (1/(2n-1)^2) e^{-((2n-1)/2a)^2 \pi^2 Dt} \quad \text{---------(19)}.$$

It is clear that equation 19 should be applied to the drying of wood only when the air velocity is sufficiently high and the wood thickness, 2a, sufficiently great that the resistance to moisture removal from the surface is negligible compared to the resistance to internal diffusion. For the drying of thin veneers it cannot give valid results nor can it give good results for the drying of boards unless the air velocity is reasonably high. Newman's equation 15 however can be applied even for thin material and low air velocities if the surface emission coefficient S and the internal diffusion coefficient D are constant.

It should be emphasized however that neither of these coefficients is necessarily constant during the drying of wood. This is particularly true when the wood is above fiber saturation. For instance the coefficient of surface emissivity S undoubtedly varies when the surface concentration is above the hygroscopic range for the reason that there is extremely little variation in the vapor pressure of wood from fiber saturation to complete saturation. Therefore, while the term $(C_a - C_e)$ in equation 15 decreases considerably as the surface concentration C_a decreases from high initial values to those near fiber saturation, the actual vapor pressure remains essentially constant if the temperature remains constant. Therefore the drying rate or flux F, which is determined in large part by the vapor pressure difference between the wood surface and the drying air, also remains constant during the initial stages of the drying of wood. If the flux F is constant and if $C_a - C_e$ decreases, then S must increase when C_a decreases from the high initial green values to those near the fiber-saturation point. The constant-rate period of drying, postulated by Sherwood (18) for drying materials in general, has been observed in wood at high moisture contents by Rees and Buckman (16) for longitudinal drying

[4] In terms of moisture concentration, $\bar{E}$ is equal to $(\bar{C} - C_e)/(C_i - C_e)$, where $\bar{C}$ is the average moisture concentration of the specimen at the time t, and C_e and C_i have the same significance as in equation 16. $\bar{E}$ can also be defined approximately in terms of moisture content M. Thus $\bar{E} = (\bar{M} - M_e)/(M_i - M_e)$, where M_i, M_e, and $\bar{M}$ are, respectively, the initial moisture content, the final equilibrium moisture content, and the average moisture content at the time t.

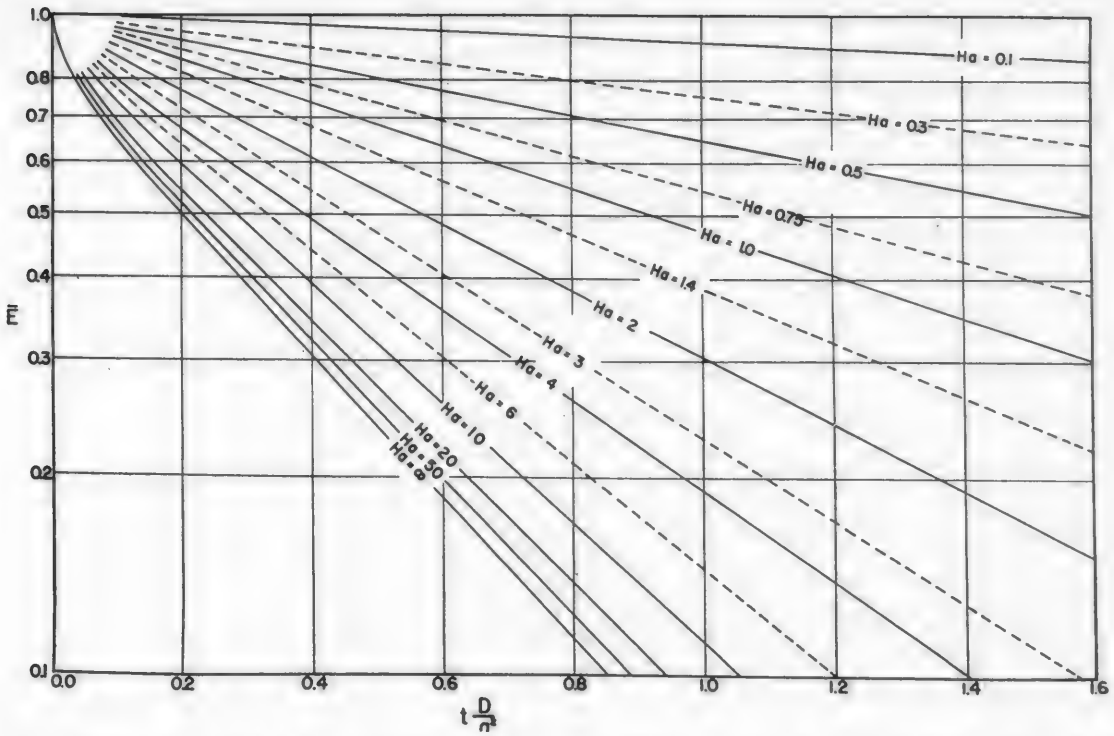

Figure 4.—Graphical representation of Newman's solution (equation 18) to the unsteady-state diffusion equation. E, the fraction of evaporable water remaining in the wood is shown as a function of tD/a², the dimensionless term which appears in equation 18, for different values of Ha. The solid lines are taken directly from Newman's data but the broken lines have been interpolated graphically.

in 5 cm long specimens (where the wood surface is maintained close to fiber-saturation by the high internal rate of movement), and by Maku (11) for the transverse drying of thin specimens (0.2 cm and 0.5 cm), but not for thicker specimens (1.0 cm and 3.0 cm). Fleischer (8) also observed a constant-rate period in some of his veneer-drying experiments as did Bethel and Hader (3), also for veneers.

Although Newman's equations and curves are probably not valid above fiber saturation, they may be applicable in the hygroscopic range provided that S and D are essentially constant with moisture content in this range. The writer has found little information on methods for measuring the surface emission coefficient S and this offers a fruitful field for investigation. Egner (7) investigated the behavior of the surface emission coefficient for spruce which was drying in still air, and also for the case where air circulation was provided. He found that the coefficient of emission was two to three times as high in air which was agitated compared to the value for still air. Egner did not measure the air velocity and he defined his coefficient in terms of the concentration of water per gram of dry air rather than per cubic centimeter of wood.

The infinite series represented by equation 19 is rapidly convergent and, except for short drying times, it reduces essentially to the first term, that is, the term for which n = 1, so that

$$\bar{E} = (8/\pi^2)\, e^{-\pi^2 Dt/4a^2} \quad \text{-----(20).}$$

Equation 20 can be solved for D in terms of the slope of the logarithm of $\bar{E}$ against time so that

$$D = -2.303(4a^2/\pi^2)\, d \log \bar{E}/dt \quad \text{----------(21),}$$

which is the equation used by Sherwood and Comings as reported by Stamm (19). Equation 18 can be used by plotting log $\bar{E}$ as a function of time for a specimen which is drying, and solving for the average internal diffusion coefficient D. It should be emphasized again, however, that the use of equations 19, 20, and 21 is valid only if the surface resistance to moisture emission is negligibly low compared to the internal resistance to diffusion.

The use of Figure 4 to determine the coefficient D requires the measurement of the time *t* required for $\bar{E}$, the average fraction of evaporable water remaining in a board which is drying from its two faces only, to be reduced to some arbitrary value, say $\bar{E} = 0.5$. The value of Dt/a^2 which is associated with $\bar{E} = 0.5$ is obtained from the particular curve of Figure 4 which applies. Usually, if the boards are sufficiently thick and if the velocity of the drying air is adequate, the curve for Ha = ∞ is used, which corresponds to Tuttle's or Sherwood's equations. After Dt/a^2 has been obtained D can be calculated since *a*, the half-thickness of the drying specimen, and *t*, the time required for $\bar{E}$ to decrease to 0.5, are known. If *a* is measured in centimeters and *t* in seconds, the coefficient D has units of square centimeters per second.

The use of the Ha = ∞ curve when Ha has a low value, such as is the case for boards dried under conditions of low air velocity, gives values for D which are too low. Under these conditions one would expect to find that the values of D obtained for thin specimens are lower than those determined on thicker specimens. If D is calculated for a series of specimens of the same material of varying thicknesses, dried under conditions of low air velocity, using the curve for Ha = ∞, it is anticipated that the values of D thus obtained should increase with increasing thickness. This is borne out by the data of Ogura (14) who used the results obtained from equation 19, which neglects surface resistance. For example, Ogura found that D was 0.0021, 0.0045, 0.0061, and 0.0073 square centimeters per hour for specimens whose thicknesses, respectively, were 0.21, 0.51, 0.81 and 1.11 centimeters. It is interesting to note that Ogura's data were obtained from tests in which no air circulation was provided, thus H undoubtedly had a rather low value.

Unsteady-state Diffusion with Variable Coefficient: The differential equation of moisture diffusion which must be solved for the case where D varies with moisture concentration C is

$$\partial C/\partial t = \partial(D\,\partial C/\partial x)/\partial x \quad \text{---(22)},$$

which reduces to equation 14 when D is constant. Unfortunately there is no general solution to equation 22 analogous to that for equation 14 as given by equations 16 or 18, where the surface emission is considered to be finite. There are however a few numerical solutions for the case where surface resistance is neglected. Barrer (1) reports that Boltzman obtained a solution for the semi-infinitely thick specimen ($x = 0$ to ∞) where the coefficient is assumed to vary in a particular way with x, and Crank and Henry (4) have recently obtained numerical solutions for equation 22 for a number of cases where the diffusion coefficient D varies in certain particular ways with the concentration C, also for the semi-infinite condition.

Crank and Henry (5) have also published a method for determining empirically the variation of D with concentration C by observation of the curve of average evaporable water $\bar{E}$ remaining in the specimen as a function of time t. This curve is then compared with the theoretical curve where D is presumed to be constant (shown in Figure 4 for $Ha = \infty$), and by a series of approximations the behavior of D as a function of C is obtained. There is not adequate space here to discuss this method more completely, but it does offer considerable promise as a technique for measuring D for wood where D varies with C. This method has been applied by Crank and Park (6) to the determination of D as a function of C during the diffusion of chloroform through polystyrene which it swells in a manner similar to that in which water swells wood.

Egner (7) derived from equation 22, which is the differential form of the diffusion equation with variable coefficient D, the relation that

$$D = (\partial(\textstyle\int_o^x C\,dx)/\partial t)/(\partial C/\partial x) \quad \text{----------(23)},$$

which is the basic equation that he used to determine the variation of D with moisture concentration C[5] in spruce specimens which were drying at various temperatures. Equation 23 can be derived directly from equation 16 by performing the operations indicated in equation 23 on equation 16.

Egner's method requires knowledge of the moisture distribution in a board at various times during the drying period. Referring to Figure 5, where a family of curves, showing hypothetical moisture concentration distributions in a drying board at various times t_1, t_2, t_3, etc. are given, the integral $\int_o^{2a/5} C\,dx$, where $x = 2a/5$, at the time t_3, is the area under the curve $t = t_3$, $\partial C/\partial x$ is the slope of the moisture distribution curve at time t_3 at the point $2a/5$. If the area denoted by the integral $\int_o^{2a/5} C\,dx$ is determined for the times t_1, t_2, t_3, etc., and plotted against t, a curve similar to that shown in Figure 6 is obtained. The slope of this curve at t_3 is $\partial \int_o^x C\,dx/\partial t$ at $x = 2a/5$ and $t = t_3$, which, when substituted into equation 23, together with $\partial C/\partial x$ at the same point, gives D for the concentration C, shown in Figure 5. Several other workers have used Egner's method directly, including Schluter and Fessel (17), Ogura (15), and Maku (11).

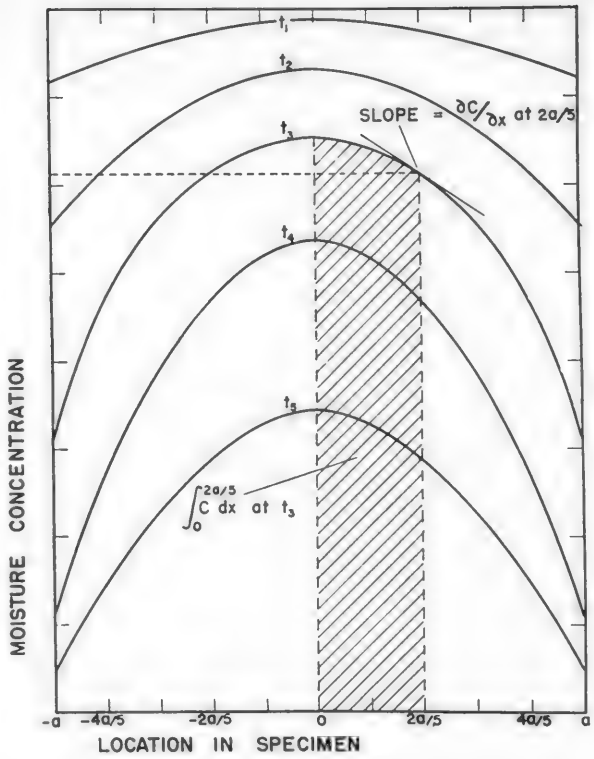

Figure 5.—Family of curves showing hypothetical moisture distribution curves for various times t in a wood specimen which is drying from the two opposite faces at which $x = \pm a$. The shaded area represents the integral $\int_o^{2a/5}(C\,dx)$ at the time t_3. The corresponding slope $\partial C/\partial x$ of the moisture distribution curve is shown for $x = 2a/5$ and time t_3.

It is possible to obtain the coefficient of surface emission S from data which show the changes in moisture distribution with time, such as are required for Egner's method for finding D; particularly if the surface moisture concentration C can be obtained. The flux F of moisture emission at the surface ((1/A) (dq/dt)) at any time t is equal to the rate at which moisture is lost from the entire specimen per unit area A of drying surface. This is equal to the time rate of change of the area (see Figure 5) under the entire curve for any time t (for drying from a single surface) between the center of the board ($x = 0$) and the surface ($x = a$), or

$$(1/A)\,dq/dt = \partial(\textstyle\int_o^a C\,dx)/\partial t \quad \text{----------(24)}$$

which can be obtained from the slope of the curve of $\int_o^a C\,dx$ against time t similar to that shown in Figure 6. If equation 15 is applied equation 24 is transformed into

$$S = (1/(C_a - C_e))\,\partial(\textstyle\int_o^a C\,dx)/\partial t \quad \text{----------(25)}$$

which together with Egner's equation (equation 23) permits both S and D to be determined simultaneously from the same data.

Bateman, Hohf, and Stamm (2) have used a variation of Egner's method to measure D_m for Sitka spruce specimens in which drying was permitted to take place from one surface only by coating all the other surfaces. Their specimen thickness, therefore, corresponds to the half-thickness *a* of a sample which is dried from two opposite faces. Figure 7 shows a typical moisture distribution curve, in terms of C, such as these workers obtained at some arbitrary time t. The rate of moisture loss from the surface of the specimen at this time t, therefore, is given by equation 24 and when this is combined with Egner's

[5] Egner used the form of equation 23 which gives D_m in terms of the change in the moisture content (M) distribution since he was working in those units.

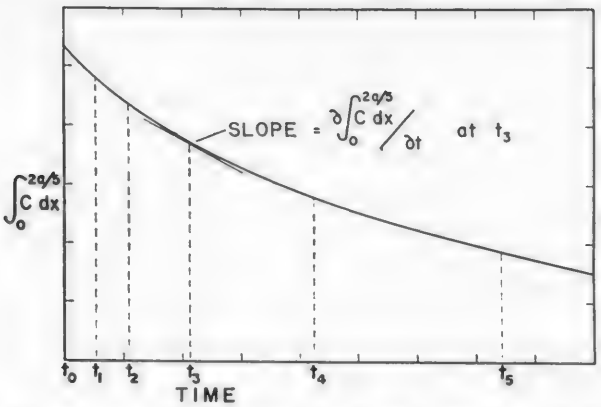

Figure 6.—Representative curve showing the integral $\int_0^{2a/3}(C\,dx)$ as a function of time t. The time rate of change of this integral is $\partial(\int_0^{2a/3}C\,dx)/\partial t$, which, for the time t_3, is the slope of the curve at t_3, as is indicated in the figure.

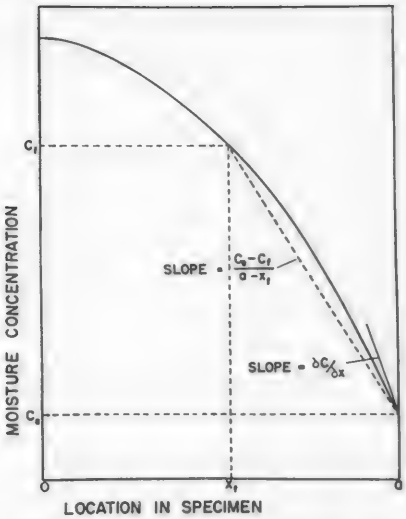

Figure 7.—Representative unsteady-state moisture distribution curve for a specimen of thickness *a*, which is drying only from the one surface where $x = a$. The mean secant gradient $(C_e - C_f)/(a - x_f)$ is shown by the broken line connecting the surface moisture concentration C_e and the moisture concentration C_f at the fiber-saturation point. The slope $\partial C/\partial x$ is shown for $x = a$.

equation 23, for $x = a$, the steady-state equation is recovered, or

$$D = (1/A)(dq/dt)/(\partial C/\partial x) \qquad (26)$$

which was used by Bateman, Hohf, and Stamm. However, it should be noted that the gradient $\partial C/\partial x$ should be taken at the surface where $x = a$. Bateman, Hohf, and Stamm used the mean secant gradient between the moisture concentration C_f at the fiber-saturation point and the surface moisture concentration, which they assumed to be equal to C_e, the equilibrium moisture concentration of the drying air, since the rate of air circulation which they used was very high. Their gradient, therefore (indicated in Figure 7 by the broken line which connects the points on the curve that correspond to C_f and C_e), was $(C_e - C_f)/(a - x_f)$; where x_f is the value of x at the fiber-saturation point; and was consistently lower, numerically, than $\partial C/\partial x$ at the surface ($x = a$), as Figure 7 shows. Therefore the values for D obtained by these workers are too high and should be multiplied in each case by the factor $((C_e - C_f)/(a - x_f)(\partial C/\partial x))$ in order to obtain the correct coefficient for the moisture concentration C_e of the surface layers.

Voigt, Krischer and Schauss (21) employed an unsteady-state method similar to that of Egner except that they used the average rate of change of the integral $\int_0^x C\,dx$ between two successive times t, rather than the instantaneous rate used by Egner. It appears that their method for finding D is no improvement over Egner's method and is, in fact, more cumbersome. In addition to their unsteady-state method, Voigt, Krischer, and Schauss (21) also used a rather unique steady-state method for finding the fraction of moisture movement through wood which takes place in vapor form, compared with the fraction which moves as a liquid, at various temperatures and moisture contents. However, this technique does not in itself yield an overall coefficient D of moisture diffusion, and therefore is not discussed in detail in this paper, although it is of considerable importance as an experimental method for ascertaining the mechanism by which water moves through wood.

Summary

The internal moisture diffusion coefficient D for wood and the coefficient S of surface moisture emission are the factors which determine the moisture gradients that exist in wood during the drying process. The diffusion coefficient D appears in one of three general forms depending upon whether the moisture gradient in the wood is defined in terms of moisture concentration C (weight of water per unit volume of the wood), moisture content M (weight of water in percent of the dry weight of the wood) or water vapor pressure h (water vapor pressure of the wood). The relationship between these three forms is given.

The diffusion coefficient D can be determined by steady-state methods in which the moisture distribution in the wood remains constant with time, or by unsteady-state methods in which the moisture distribution changes with time. The steady-state methods are more time consuming experimentally but permit the use of relatively simple mathematical relationships between moisture distribution and the diffusion coefficient, even when the diffusion coefficient varies with the moisture concentration of the wood. The unsteady-state methods require less experimental time than the steady-state techniques but the mathematical relationships between moisture distribution, time, and the diffusion coefficient are more complex. Analytical mathematical solutions for the unsteady-state diffusion equation for wood of finite thicknesses are available only for the case where the diffusion coefficient D and the surface emission coefficient S are assumed to be constant with moisture concentration.

A number of steady-state and unsteady state methods for finding the coefficient D are described and analyzed with respect to their advantages and disadvantages. Some of these methods have not been applied to wood but they show promise of considerable usefulness for future research.

Acknowledgement

"Acknowledgment is rendered to Dr. Frederick F. Wangaard, Prof. of Forest Products at the Yale University School of Forestry, under whose guidance this study was made."

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Changes in Weight and Strength of Sitka Spruce Associated with Decay by a Brown-Rot Fungus, *Poria monticola*[1]

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The standard method for determining resistance to decay of wood and wood products is by measurement of loss in dry weight. This paper gives the results of a study correlating loss in dry weight with loss in strength. Sitka spruce beams decayed in pure culture with a brown-rot fungus, *Poria monticola*, were tested at five different intervals over a two-week exposure period. The effect of the fungus on fiber stress at proportional limit, modulus of rupture, modulus of elasticity, work to proportional limit, work to maximum load, and equilibrium moisture content associated with loss in dry weight is discussed.

THE SERVICEABLE LIFE of many wood products is limited by the decay resistance of the wood. However, the rate of fungal activity producing decay is influenced greatly by the particular conditions under which a specific product is used and may not be appreciable even after years of service. Consequently an accelerated laboratory test involving pure cultures of selected fungi and uniformly controlled conditions of exposure is commonly used in determining the natural decay resistance of different woods or the relative effectiveness of various preservatives in treated wood. Under these conditions substantial deterioration of non-durable species occurs in as short a period as four months. Loss in dry weight is used currently to measure decay resistance in such laboratory tests.

One objection to the weight-loss method of determining decay resistance is that it is not sensitive enough for evaluation of the effect of decay on strength properties during initial stages of attack. This objection takes on special significance when brown-rot organisms are used in testing as these fungi are known to induce substantial losses in shock resistance even in the early stages of decay. Furthermore, it seems likely that decay-resistant woods which show relatively little weight loss after several months of exposure have nevertheless been altered substantially in some of their properties.

It is the purpose of this study to determine the relationship between loss in dry weight and loss in strength in static bending for a common brown-rot fungus which frequently attacks the wood of Sitka spruce, both in the living tree and in service. It is felt that a study showing the strength properties

[1] A 1954 "Wood and Wood Products" Graduate Award entry written while author was a student at Yale University. The Award is sponsored by Vance Publishing Co., Chicago.

first affected, and the magnitude of this effect, will add greater significance in terms of strength reduction to weight changes as determined by accelerated laboratory tests.

Review of Pertinent Literature

Decay of wood involves a chemical breakdown of the cell wall as a result of the action of enzymes secreted by the decay-causing fungus. Although this process is complex, and not as yet well understood, it has been established that wood-destroying fungi fall into two classes based upon the fraction of the wood that they destroy. The group referred to as the white-rot fungi attacks both cellulose and lignin, but prefers to act on the lignin. This attack appears to be a process of both hydrolysis and oxidation (4). The other class, referred to as the brown-rot fungi, breaks down wood cellulose by means of a process similar in effect to that of a mild acid hydrolysis (5).

The attacking fungus moves through the wood, converting the complex wood structure into simple sugars usable for food by means of enzymes. The initial stages of fungal penetration often show the formation of "bore holes" or digested areas through which the actual hyphae of the fungus pass. The secretion of enzymes precedes the hyphae, thus causing a chemical breakdown of the wood before the actual entrance of the hyphae (13).

Poria monticola, used in this study, is chemically defined as a brown-rot fungus, and as such is known to have certain general effects on wood. In its advanced stages, a brown-rot is characterized by a brown charcoal-like residue frequently referred to as brown cubical rot or dry rot. The alkali solubility of wood infected by brown rots has been found to parallel the extent of decay. This relation does not exist in the case of white rots (5). Wood infected by brown rots also shows a rapid decline in strength properties, especially shock resistance, during the initial stages of decay, while the effects of white rots on strength during the initial stages are variable, but usually not so spectacular (6).

The fact that wood in the advanced stages of decay shows a reduction in strength properties has been known for many years. The effect brought about by decay on the mechanical properties of wood have been the subject of study since 1899. The first known work on relation of decay to strength change was conducted by von Schrenk (17) in 1899 on pecky bald cypress and incense cedar. In 1915, Abbott (1) found loss in weight, as well as in bending and crushing strength, after only six months' exposure to the white-rot fungus *Fomes pini.* His decay classes, however, were based on color variations rather than on quantitative changes in weight. In 1921, Colley (9), working with brown rots, compared tests on incipiently decayed wood from the living tree and reported a 95 percent loss in toughness and a 30 percent reduction in crushing strength after a loss in specific gravity of 10 percent. In contrast, he found that a loss of 95 percent in toughness and 70 percent in crushing strength was observed after a decrease in specific gravity of 30 percent in wood attacked by a white-rot fungus. It is evident from these early tests that a large loss in strength results from a comparatively small change in dry weight in wood attacked by brown-rot organisms. The differential effects of the same fungus on different strength properties can also be seen.

Longyear in 1926 (11), noting that reference had been made to lightness in decayed wood by different workers since 1875, attempted to correlate the results of mechanical tests with weight loss due to decay. In his study he made no attempt to determine the fungi causing the decay, but rotted his specimens in damp loam soil. These tests are important, not only because they were the first to atempt to correlate a quantitative weight loss value with loss in strength, but because they showed that in some cases there is a significant loss in strength before there is any loss in weight.

In 1931 Cartwright et al. (8) attempted to correlate weight loss and alkali solubility with reduction in strength caused by the brown-rot fungus *Trametes serialis*[1] on Sitka spruce. In these tests the wood was decayed in pure culture and tested in static bending. No measurable weight loss was discovered until the fifth week; however, by the second week, a reduction of 15 percent had occurred in the modulus of rupture, and by the fourth week a typical brash break was observed. As a result of these tests, Cartwright concluded that in the case of brown rots, loss in strength due to decay is more closely related to increasing alkali solubility than to loss in dry weight. In 1935 Armstrong (3) repeated these tests and arrived at the same conclusions. Solovieff in 1936 (19) and Vanine in the same year (21) studied the effects of the incipient stages of decay caused by two white-rot fungi (*Fomes connatus* and *F. annosus*) on strength and found them to have little effect.

In 1936 Cartwright et al. (7) studied the effects of the white-rot fungus *Polyporus hispidus* on English ash. After two weeks of exposure they found a negligible weight loss, a reduction of 2 percent in modulus of rupture, and a reduction of 20 percent in toughness. After ten weeks, toughness was reduced by 90 percent, crushing strength was reduced by only 10 percent, and the modulus of elasticity was not reduced at all. The loss in strength was not found to be related to a chemical change as was the case with the brown rots.

Scheffer (14) in 1936, working with the white-rot organism *Polyporus versicolor* on sweet gum, found strength to be reduced more rapidly than specific gravity during the initial stages of decay in several properties, but not in fiber stress at proportional limit, work to proportional limit, and modulus of elasticity in bending. In a study in 1941 (16), the same author found that the brown rot caused by *Polyporus schweinitzzi* affected all strength properties earlier and more drastically than did the white rot produced by *Fomes pini.* Specific gravity was not affected in the initial stages of the white rot, whereas, in the brown rot studied, specific gravity appeared to be affected but changes were difficult to detect because of the natural variation in specific gravity within the species.

In 1940 Trendelenburg (20) suggested that relative decay resistance be determined by loss in strength in impact bending tests rather than by loss in dry weight. The brown rot used in his study was found to reduce strength in toughness by 80 percent, while dry weight was reduced only 10 percent, in thirty days. His technique has met with opposition because of the difficulty of securing uniform decay.

Material Tested

Sitka spruce (*Picea sitchensis*) was selected for testing in this study because of the low decay resistance and uniform density of its heartwood. These were necessary requirements to insure uniformity of decay. Test specimens were taken from a single piece of medium density, air-dry, Sitka spruce. The material was true quarter-sawn, straight-grained, and averaged sixteen rings to the inch.

From this single stick were sawn 25 pieces 3/8 by 3/8 inch, which were later planed to 1/4 by 1/4 inch. Four end-matched 4 1/2-inch long test specimens were cut from each piece so that the two center specimens served as end-matched controls for the two outer test specimens. The 100 specimens were divided into five groups, each consisting of ten test specimens and their individual controls. The groups were numbered 1 through 5. The controls were lettered A through J, and the test specimen which was end-matched with

[1] It appears almost certain that the fungus Cartwright and his colleagues used was actually *Poria microspora* (Nobles in Canad. Jour. Bot. Sect. C, 21: 211–234. 1943.), now called *P. monticola* (Overholts in Mycologia 38: 674–676. 1946.)

each of the controls was given the same letter and circled. Thus specimen no. 3C was the control specimen for the circled C test specimen in the third exposure group.

The fungus used in this study was *Poria monticola*[2]. The fungus was cultured in six-inch French square bottles on malt agar in a constant temperature room kept at 25° C. After two weeks the agar was covered with a uniform mat of mycelium.

Decay Procedure

Following the cutting and marking of the samples, each test specimen was end-dipped in a thermosetting resin[3] to eliminate excessive end penetration by the fungus. All specimens were conditioned in an oven at 40° C. for five days, after which they were removed to a desiccator and promptly weighed to the nearest 0.0001 gram on an analytical balance.

Each test specimen was then placed with the numbered radial side down on a sterile bent glass rod in a bottle containing the cultured fungus. The radial side was placed down over the fungus to allow for easy penetration along the springwood zones. The bottles were again placed in the constant temperature room and, at the end of each exposure period, ten bottles were removed. Groups 1 to 5 were exposed for 2, 4, 6, 10, and 14 days, respectively. Except for exposure to the fungus, the controls were handled in the same manner as the test specimens.

At the end of each exposure period the specimens were given a visual rating as to the extent of mycelial cover, contamination, and presence or absence of mites. The specimens were then removed from the bottles, the mycelium wiped off with a mercuric chloride solution, and they were again placed in the 40° C. conditioning oven. After five days the specimens were again weighed in the manner described above. The weight loss was expressed as a percentage of adjusted initial dry weight[4].

Mechanical Testing Procedure

After weighing, the samples were conditioned to a uniform equilibrium moisture content over a saturated solution of sodium nitrite (relative humidity approximately 63 percent). The conditioning was done in a sealed desiccator kept at 90° F. with an electric fan for air circulation. The specimens were conditioned until they reached a constant weight, at which time it was assumed that all specimens had come to equilibrium. At the time of testing the specimens were removed from the conditioning chamber two at a time, a decayed sample and its end-matched control, and placed in a plastic bag which was kept closed until the specimens were ready for testing. Upon removal from the bag, the width and depth of the specimen were measured to the nearest 0.001 inch on an Ames dial comparator, and the specimen was placed immediately in the testing machine. Static-bending tests of 1/4 by 1/4-inch specimens loaded over a 3 1/2- inch span were carried out on a Baldwin hydraulic testing machine having a load sensitivity of 0.2 pound. A platen speed of 0.012 inch per minute and a bearing head of 0.375-inch radius were used. The span-depth ratio of 14 to 1 was mantained, radius of curvature of bearing block and platen speed were reduced proportionately from standards prescribed by the American Society for Testing Materials for 2 by 2 by 30-inch beams. In testing very small specimens such as these, however, it was felt that the chance occurrence of spring- or summerwood, when the load was applied on the tangential face as called for in the standard test method, would introduce considerable variability. For this reason, the tests were conducted with the load on the radial face to give more uniform results. The load was applied to the same radial face of both test and control specimens. Deflections were taken to 0.001 inch by means of an Ames dial at load increments of two pounds.

Upon completion of the test, a specimen from the region of the break was removed and immediately weighed to determine the moisture content. A second section was cut from the decayed samples for determination of the specific gravity of the outer 1/16-shell and the remaining core. In the latter, a tangential slice corresponding to shell thickness was first taken from both tangential faces of the specimen and discarded. The radial surface shells and the core were dried in an oven at 100° C., weighed on an analytical balance, and their volume measured with a Breuil mercury volume meter. The specific gravity of the controls was determined from the moisture content sections.

Load-deflection diagrams were plotted for each specimen, and fiber stress at proportional limit, modulus of rupture, modulus of elasticity, work to proportional limit, and work to maximum load were determined.

The small beams used for this study proved very satisfactory, both from the standpoint of testing procedure and uniformity of results. The average weight of the specimens was about 2 grams, of which about 3.5 percent represented the resin endcoat. In order to obtain the true dry weight, the adjusted initial weight as well as dry weight after decay was reduced by the weight of the resin.

Each mechanical test required about fifteen minutes to run and, during this time, no provision was made to reduce moisture loss in the specimen. This loss was found to be virtually negligible, however, and since both control and test specimens were handled together and tested at the same time, any slight moisture loss that did occur was essentially the same in both specimens.

The equilibrium moisture content of the undecayed control specimens over the saturated salt solution was about 9.5 percent. The decayed specimens came to equilibrium at a somewhat higher moisture content. Therefore, for comparison, all strength values were adjusted to a 12 percent moisture content, using a fiber saturation point of 27 percent. Adjustment was made according to the method outlined by Wilson (23).

Although originally selected visually for straightness of grain, it was evident after testing that some cross grain was present in a number of specimens. The combined slope of grain was measured using a scribe and etched templet, and for those specimens in which the combined slope of grain was found to be greater than 1 in 20, strength values were adjusted insofar as possible to correspond to a slope of 1 in 20. A few test results based on specimens with a slope steeper than 1 in 15 were invalidated. The basis for adjustment was the work done by Wilson (22) on the effect of spiral grain on the strength of Sitka spruce. The only strength values for which a percentage reduction in strength as a result of slope of grain was given by Wilson are modulus of rupture, modulus of elasticity, and work to maximum load. Consequently no adjustment for cross grain was made in test values for fiber stress at proportional limit and work to proportional limit.

Results

Average specific gravity (oven-dry weight and volume) for the fifth period control specimens was found to be 0.41. In determining the specific gravity of the test specimens for this same group the shell was found to average 0.40 (0.37–0.43), a negligible difference from that of the core which averaged 0.41 (0.37–0.44). If the weight loss as indicated by a specific gravity difference between the shell and core had been found to occur primarily in the outer 1/16-inch shell, the average weight loss of the specimen would not have shown the true magnitude of the loss in weight in the zone effectively resisting applied loads in static

[2] Madison culture No. 698.

[3] Penacolite G–1131 manufactured by Koppers Co., Inc.

[4] Adjustment of initial dry weight was based on weight changes in the control specimen resulting from fluctuations in atmospheric humidity.

bending. As far as could be determined from the specific gravity tests, the decay caused a uniform weight loss throughout the test specimen.

Table 1 shows the weight change by exposure periods. Average values are plotted against a zero weight change line in Figure 1. The footnotes in Table 1 are the visual ratings given the mycelial cover on the specimens at the end of the test period.

In Table 2 the moisture contents for the control and test specimens are shown, and Figure 1 illustrates the equilibrium moisture content expressed as a percentage of the control moisture content. Figure 1 also includes the weight change line to show the magnitude of the change.

Table 3 shows final strength values by exposure groups after all adjustments for slope of grain and moisture content were made. The groups initially contained 10 test specimens and 10 controls, but the values which were invalidated because of excessive slope of grain have been omitted. Figure 2 shows strength values for those properties that were not significantly changed by the action of the fungus over the two-week period plotted on a scale in which the control is taken to be 100 percent. Figure 3 shows work to maximum load and modulus of rupture values plotted in a similar manner. In both figures weight changes are plotted to show the relative magnitude of the change in other properties.

Discussion of Results

After exposure to the fungus for four days, the test specimens showed a weight increase of 0.05 percent, and by this time the mycelium covered the entire lower surface of the specimens and extended halfway up the sides. "Student's t" test as applied to this change in weight showed it to be significant although it was not until the six-day exposure period that the increase in weight became highly significant. By this time the fungus had begun to alter the cell wall so that a higher equilibrium moisture content was obtained upon conditioning over the saturated solution of sodium nitrite. This increase can be seen in Table 2, and from Figure 1 it is evident that this increase in equilibrium moisture content continued through the second week, although by this time it had begun to level off.

Scheffer in 1936, when working with the white rot caused by *Polyporus versicolor* noted a reduction in the equilibrium moisture content. As previously mentioned, the fungus used in this study is a brown rot organism which brings about the breakdown of wood substance through a reaction similar to that of a dilute acid hydrolysis.

Table I. Weight change at various early stages of decay of Sitka spruce expressed as a percentage of adjusted initial weight./1

Specimen designation	Group I 2 days' exposure/2	Group II 4 days' exposure/3	Group III 6 days' exposure/4	Group IV 10 days' exposure/5	Group V 14 days' exposure/5
A	+0.11	+0.11	+0.15	0.06	1.34
B	+0.05	0.08	+0.42	+0.05	1.97
C	+0.04	+0.09	+0.35	0.00	2.29
D	+0.05	+0.11	+0.19	+0.06	1.67
E	+0.05	0.02	+0.34	0.32	2.36
F	0.05	+0.14	+0.22	+0.05	2.03
G	0.00	0.03	+0.18	+0.19	2.06
H	+0.08	+0.05	+0.25	0.03	1.90
I	0.07	+0.06	+0.42	0.01	2.30
J	+0.04	+0.11	+0.27	0.43	2.09
Average/6	+0.03	+0.05*	+0.26**	0.05	2.03**

/1 Weight changes preceded by plus (+) sign indicate weight increase.
/2 No mycelium on test specimen.
/3 Mycelium covered lower surface and part of sides of specimen.
/4 Light layer of mycelium covering entire surface of test specimen.
/5 Specimen covered with a heavy growth of mycelium.
/6 * - Significant, 5 percent level.
** - Highly significant, 1 percent level.

Table II. Equilibrium moisture content of Sitka spruce at various early stages of decay.

Specimen designation	Group I 2 days' exposure		Group II 4 days' exposure		Group III 6 days' exposure		Group IV 10 days' exposure		Group V 14 days' exposure	
	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test
A	9.39	9.86	8.74	9.60	8.91	10.04	10.62	13.53	10.24	11.48
B	9.46	9.57	9.26	9.55	9.30	10.36	10.12	10.70	10.12	10.84
C	9.57	9.79	9.38	9.86	9.09	9.76	9.49	10.10	10.29	11.53
D	9.09	9.74	10.11	10.06	8.79	9.57	9.20	9.87	9.71	11.09
E	9.38	9.35	9.94	10.67	8.37	9.44	9.52	10.39	10.28	11.53
F	9.20	9.30	9.85	9.96	8.52	9.43	9.45	10.42	9.77	11.34
G	9.07	9.13	8.46	8.98	8.99	10.06	9.19	9.78	9.52	10.50
H	8.62	8.87	8.55	9.16	8.91	9.34	8.66	9.43	9.71	10.71
I	8.29	9.35	9.37	9.87	8.64	9.58	8.78	9.59	9.00	10.11
J	8.60	9.03	8.72	9.38	9.14	9.92	9.63	9.85	9.67	10.48
Average/1	9.07	9.40	9.24	9.71**	8.87	9.75**	9.47	10.37**	9.83	10.96**

/1 ** Highly significant, 1 percent level.

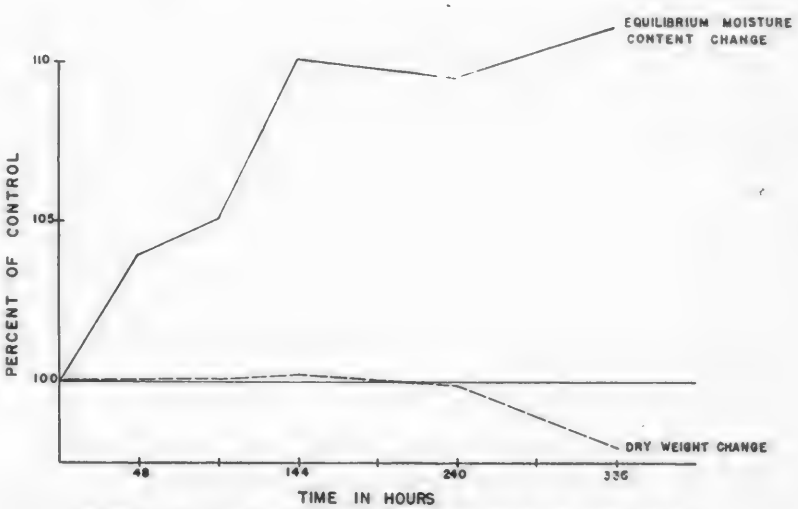

FIGURE 1. AVERAGE WEIGHT CHANGE AND INCREASE IN EQUILIBRIUM MOISTURE CONTENT BY EXPOSURE PERIODS.

This hydrolysis occurs in the cellulose chains which presumably then afford a greater opportunity for the adsorption of water molecules. Therefore, it can be seen that the results of this study do not conflict with those of Scheffer who worked with a white-rot organism which is thought to attack lignin primarily during the initial stage of decay.

The change in equilibrium moisture content brought about as the fungus progresses helps to explain a condition which has been observed many times in decay testing and has previously been attributed to experimental error or to an unknown cause. This is a weight gain which is sometimes observed in extremely durable woods after the standard four months' exposure period. This is most noticeable in woods affected by brown rots, although it does occasionally occur also in the case of white rots. From the results of this study, it appears that this weight gain can be attributed, in part, to an alteration of the cell wall such that, upon reconditioning, the equilibrium moisture content is significantly increased, thus causing the weight gain. This gain can readily be seen in Table 1 where the 6-day group shows an average weight increase of 0.26 percent. At the end of this exposure period, the entire specimen was covered with a light layer of mycelium. Another factor contributing to increased weight is an increase in chemically combined water of constitution as a result of hydrolysis.

The group of specimens exposed for 10 days shows the weight gain observed at an earlier stage largely to be masked by a corresponding loss in weight due to progressive fungal activity. At this time, the test specimens were entirely covered with a uniformly heavy layer of fungus mycelium. By the end of the 2-week period, an average weight loss of 2.03 percent had occurred and the equilibrium moisture content of the decayed specimens had increased 11.5 percent over that of the control specimens, or an increase in the actual equilibrium moisture content from 9.83 percent to 10.96 percent.

The average strength values by periods were computed and the "Student's t" test was applied to the results to determine the significance of the differences. No significant difference was found in any of the strength changes except in the fifth group, those specimens exposed for two weeks. At this time the modulus of rupture and work to maximum load values of decayed specimens were found to differ significantly from corresponding control values as may be seen in Figure 3. Most changes in wood quality are first recorded in shock resistance, which is best meas-

Table III. Strength values of Sitka spruce adjusted to 12 percent moisture content for various early stages of decay./1

Fiber stress at proportional limit (p.s.i.)		Modulus of rupture (p.s.i.)		Modulus of elasticity (1000 p.s.i.)		Work to proportional limit (in.-lb./cu. in.)		Work to maximum load (in.-lb./cu. in.)	
Control	Test	Control	Test	Control	Test	Control	Test	Control	Test
Group I - 2 days									
7760	7930	11100	11750	1310	1380	2.57	2.54	13.5	13.3
7380	7150	10500	10740	1190	1320	2.55	2.17	11.9	11.5
7700	7940	10700	10880	1240	1310	2.68	2.68	14.5	13.8
7860	6900	10700	10650	1315	1360	2.60	1.94	12.7	13.0
7830	6800	11600	9800	1290	1220	1.64	2.14	11.9	16.2
7860	7030	10900	10050	1310	1375	2.64	2.00	11.4	10.2
7140	7200	10280	10990	1340	1330	2.12	2.42	11.6	10.3
7950	7800	11300	10700	1470	1395	2.40	2.44	12.6	12.9
Average:									
7680	7340	10880	10695	1310	1340	2.40	2.29	12.5	12.6
Group II - 4 days									
8860	8875	12300	11300	1370	1430	3.21	3.08	12.7	12.2
7430	7340	11300	10500	1270	1320	2.42	2.28	12.9	12.2
8580	7500	10800	10300	1370	1390	2.99	2.26	12.0	12.5
7950	8400	10600	10870	1320	1180	2.69	3.30	12.5	12.8
7500	7040	10700	9720	1380	1350	2.28	2.06	13.3	9.5
7540	7740	9980	10900	1255	1400	2.54	2.39	10.1	15.9
7590	7870	9680	10440	1325	1250	2.24	2.76	8.7	12.4
8120	7350	11220	10040	1380	1210	2.76	2.49	10.8	11.2
Average:									
7950	7760	10820	10509	1330	1320	2.64	2.58	11.6	12.3
Group III - 6 days									
7240	7670	10950	10500	1150	1230	2.52	2.66	12.4	11.8
8960	7840	12000	10300	1280	1150	3.51	2.98	14.2	11.3
7000	8000	10960	10300	1330	1250	2.06	2.88	15.0	11.0
7330	8070	11000	10860	1340	1260	2.25	2.87	12.2	12.6
7325	8220	10280	10800	1345	1220	2.22	3.05	10.6	11.0
7800	7640	10360	10870	1230	1270	2.76	2.55	10.4	12.8
7700	6500	10950	10050	1370	1230	2.26	1.79	13.2	10.7
7250	7175	10300	10000	1310	1210	2.25	2.40	11.3	11.1
6600	7300	9600	10200	1210	1270	2.00	2.32	9.6	10.6
Average:									
7470	7600	10710	10430	1285	1240	2.42	2.61	12.1	11.4
Group IV - 10 days									
8760	8540	11130	12120	1380	1360	3.12	2.95	11.9	12.5
7850	7660	11400	10400	1310	1160	2.65	2.88	13.5	12.7
8160	6760	9870	9425	1280	1130	2.89	2.32	11.0	8.2
8180	8130	11530	11320	1200	1430	3.11	2.56	13.2	14.1
6630	7340	11050	10200	1240	1180	1.97	2.60	11.6	11.7
7660	7450	10540	10730	1330	1220	2.47	2.62	10.6	13.1
7080	7040	10200	9640	1320	1250	2.12	2.30	10.7	8.4
7840	7690	11200	11630	1200	1410	2.66	2.38	14.3	12.1
7850	6350	9710	9160	1210	1150	2.85	1.97	10.5	11.3
7200	7030	10020	9900	1230	1240	2.37	2.25	10.5	10.7
Average:									
7720	7400	10660	10450	1270	1250	2.62	2.48	11.8	11.4
Group V - 14 days									
7850	8000	10750	9610	1240	1310	2.78	2.77	10.8	8.4
7990	6830	9910	8860	1180	1380	2.96	1.97	10.2	7.9
8690	7190	11700	9830	1400	1410	2.99	2.02	12.0	7.2
7780	6800	10650	8460	1200	1050	2.80	2.44	11.9	7.5
8100	8000	11000	10900	1360	1200	2.67	2.30	11.3	8.6
7840	6640	10480	8580	1340	1120	2.65	2.24	10.5	8.0
8200	8060	11330	10400	1410	1470	2.66	2.54	11.6	9.5
7150	8050	10750	8900	1500	1310	1.90	2.76	10.1	7.2
Average:/2									
7950	7450	10820	9440**	1330	1280	2.68	2.38	11.0	8.0**

/1 All specimens in which slope of grain exceeded 1 in 15 have been eliminated, and all others of slopes greater than 1 in 20 have been adjusted to that slope.

/2 ** - Highly significant, 1 percent level.

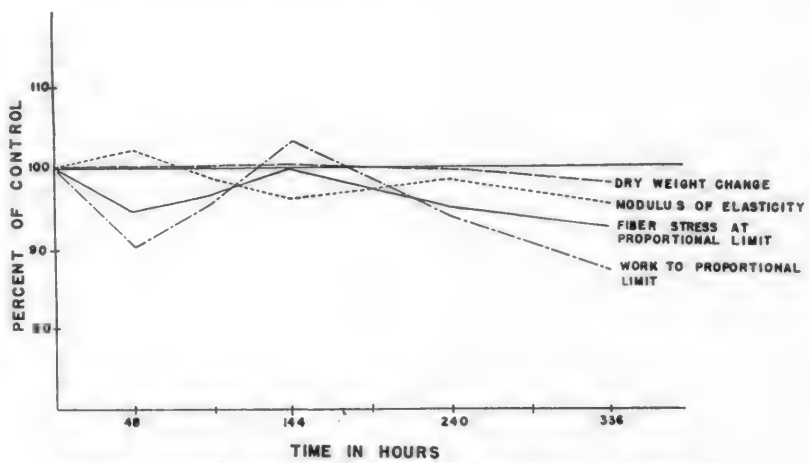

FIGURE 2. AVERAGE WEIGHT CHANGE AND CHANGES IN AVERAGE STRENGTH VALUES BY EXPOSURE PERIODS.

ured, among the properties studied here, by work to maximum load. Work to maximum load was reduced by about 26 percent while modulus of rupture showed a reduction of 13 percent. All specimens in these tests broke in splintering tension. However, in a preliminary pilot test, a reduction in weight of about 4 percent was found to be associated with a typical brash break, reducing work to maximum load by 55 percent and modulus of rupture by 35 percent.

Fiber stress at proportional limit, work to proportional limit, and modulus of elasticity were not significantly changed by the action of this fungus in two weeks, although Figure 2 indicates a downward trend in all three properties.

The reduction in modulus of rupture of 13 percent after two weeks' exposure as found in this study agrees closely with the reduction of 15 percent reported by Cartwright et al. (1931) after two weeks' exposure to the brown-rot fungus, now thought to be *Poria monticola*. However, where Cartwright found no weight loss until the fifth week, at which time there was a reduction of 48 percent in modulus of rupture associated with a 2.4 percent loss in dry weight, this study reveals a weight loss of 2.03 percent at the end of two weeks.

The present standard screening tests for wood of unknown durability using the agar block technique rates woods according to a class grouping proposed by Scheffer and Duncan in *Tropical Woods* 92 (15). This classification is:

	Percent weight loss
(A) very durable	0–10
(B) durable	10–25
(C) moderately durable	25–45
(D) non-durable	over 45

This classification is by no means standard, but it is often used. However, when strength is an important factor in the use of wood, the results of this study indicate that durability classes now in use are much too broad since a 2 percent weight loss has such a drastic effect on work to maximum load.

Summary

The effects of early decay by the brown-rot fungus *Poria monticola* on the strength properties of Sitka spruce in static bending were studied. The extent of decay was measured as the loss in dry weight of the decayed specimen expressed as a percentage of the adjusted initial weight.

Test specimens small enough to be used with existing decay equipment were designed for the study. These beams measured 1/4 by 1/4 by 4 1/2 inches. One hundred specimens were tested: five groups, each consisting of 10 test specimens and 10 end-matched controls. The specimens were decayed by exposure over pure cultures of the fungus on agar. Groups were removed from exposure to the fungus at the end of 2, 4, 6, 10 and 14 days.

The test specimen proved to be very satisfactory, both from the standpoint of ease of handling and uniformity of decay. No significant difference was found in the specific gravity of the shell and core of the decay specimen. After six days' exposure, there was a highly significant increase in equilibrium moisture content, which was reflected in an average weight increase of the test specimen of 0.26 percent over that of the control at equilibrium in an oven maintained at 40° C. Another factor contributing to the observed "dry" weight increase was the increased chemically combined water of constitution resulting from hydrolysis. Total weight loss averaged 2.03 percent at the end of two weeks. The equilibrium moisture content of the test specimens over sodium nitrite showed an increase of 11.5 percent over the equilibrium moisture content of the controls after two weeks. Expressed in other words, the decayed specimens attained an equilibrium moisture content of 10.96 percent under the same conditions for which undecayed control specimens reached an equilibrium moisture content of 9.83 percent.

No significant loss was found in fiber stress at proportional limit, modulus of elasticity, or work to proportional limit, but losses of 26 percent in work to maximum load and 13 percent in modulus of rupture were noted at the end of the 14-day period.

This highly significant loss in strength after a loss of only about 2 percent of the dry weight indicates the importance of very small weight losses in relation to strength reduction when brown rots are involved. It also points up the danger of using too broad a durability classification when rating wood to be used in places where strength is important.

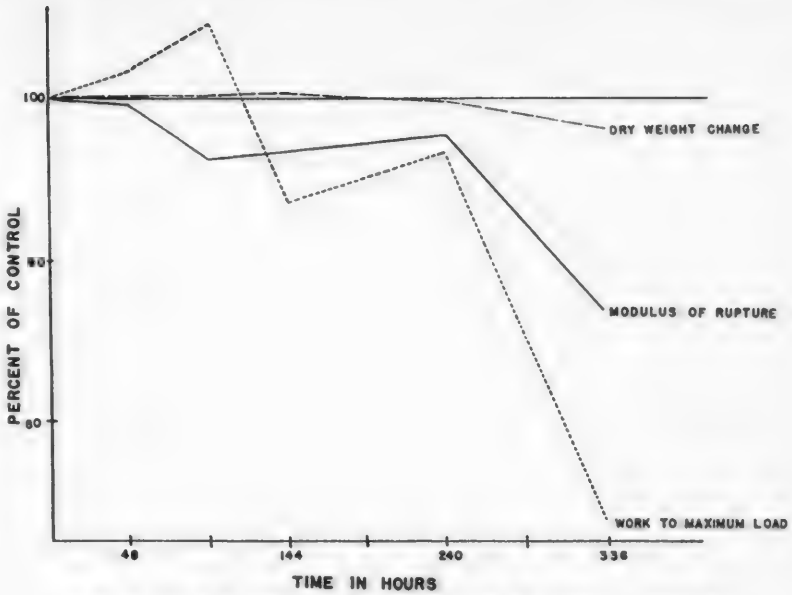

FIGURE 3· AVERAGE WEIGHT CHANGE AND CHANGES IN AVERAGE STRENGTH VALUES BY EXPOSURE PERIODS.

Acknowledgements

This study was carried out while the author was a student at the Yale School of Forestry.

The author wishes to express his appreciation to Dr. F. F. Wangaard, under whose direct supervision the work was done, for his advice and criticism during the study and in the preparation of this paper.

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The Accuracy of an Electric Moisture Detector in Green Wood[1]

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An attempt to calibrate an electric moisture detector for use in green wood was made. No positive results were obtained from this study but several conclusions concerning the factors affecting the determination of moisture content by electrical means are presented.

Introduction

IN NOVEMBER of 1953, we were given the problem of determining the moisture content of living trees using an electric moisture detector. Preliminary work was done on November 18, at the Flat Creek Unit of the School Forest of the College of Forestry, University of Idaho, at Deary, Idaho, and at Helmer, Idaho. At the time no correlation between electric moisture content and actual moisture content above 30% was noted. Since this preliminary study was on the basis of only twenty-five samples, nothing conclusive could be assumed. Since there was so little apparent correlation between the electric meter readings and those based on ovendry weight, it was decided that the study would have to include the calibration of the electric moisture detector for values above the fiber-saturation point. The difficulties encountered in this determination form the basis of this report.

The instrument used was a Delmhorst Electric Moisture Detector, Model RC–1 Serial Number 716, with an 18E electrode (Fig. 1). The electronic principle used by this instrument is that of electric conductance. Other variables remaining constant, the conductance of wood varies directly with its moisture content, and also varies in a direct relationship with the temperature. In our study, all readings were made at average room temperature, or 65° F. Temperature corrections can be applied when using the instrument at a lower or higher temperature.

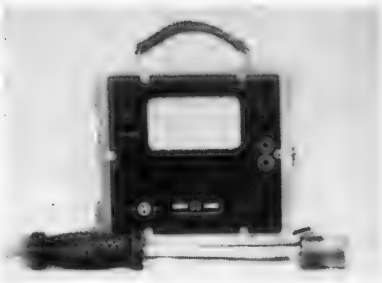

Figure 1.—Delmhorst moisture detector.

Sampling Procedure

In our study the existence of a number of variables which might affect the instrument reading were recognized. Those recognized were as follows: 1. site 2. species 3. height in tree 4. position in tree 5. time of year 6. temperature 7. specific gravity 8. rings per inch 9. percent of summerwood 10. difference in electrical resistance of heartwood and sapwood.

As many variables as possible were eliminated by the method of sampling chosen. The variable of species was eliminated by the choice of two different species, grand fir (*Abies grandis* (Dougl.) Lindl.) and lodgepole pine (*Pinus contorta* Dougl.). These species were chosen because they were readily available on the same site.

The height in the tree was accounted for by cutting four inch disks at four and one-half feet, ten feet and in most cases twenty feet from the average ground level at the base of the tree. The disks were brought back to the laboratory after cutting where they were allowed to come to room temperature in an adjusting period of twenty-four hours. The disks were then trimmed to approximately one inch in thickness, then split into quadrants and diagonal quadrants chosen to make individual specimens. The quadrants chosen were then sawed along the annual rings at approximately one inch intervals. Individual samples were then split from the resultant arcs. Final dimensions of the sample blocks were approximately one-half inch wide radially, two inches long tangentially and one inch wide along the grain. The samples were then weighed to within one-tenth of a gram and immediately after weighing the moisture content was determined by use of the electric moisture meter. The two pins of the 18E electrode were driven into the sample to a depth of about one-eighth inch. The pins were placed so the current would flow with the grain of the wood. This tended to eliminate possible variation from this source. The average lapse of time between the weighing and instrument reading was less than one minute. The samples were then ovendried to constant weight at 212° ± 5° F. to determine the moisture content based as a percentage of its ovendry weight.

As stated in the introduction, all electric moisture meter moisture determinations were made at average room temperature which eliminates variability from this factor.

The time of year that samples are taken might affect the instrument reading because of the varying concentrations of organic and inorganic salts present in the wood at various seasons. This possibility was eliminated by taking all samples in the winter season and dormant condition of the tree.

The possible variability due to specific gravity, rings per inch and percent of summerwood could not be eliminated by the sampling procedure.

The possible variation due to differences in heartwood and sapwood could not be eliminated due to an unfortunate choice of species. None of the species tested has well defined heartwood, however, in the samples chosen.

True specific gravity, specific gravity based on ovendry weight and ovendry volume, rather than specific gravity based on ovendry weight and green volume was chosen for this study, since the correlation was to be made on the basis of actual moisture content. Ovendry volume was determined by the water-displacement method. The sample blocks

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[1] Winner of 1954 "Wood and Wood Products" Undergraduate Award presented by Vance Publishing Co., Chicago, at FPRS' eighth national meeting, Grand Rapids, Mich., May 5, 6, 7, 1954.

were coated with a thin film of paraffin prior to immersion in water to prevent water from entering the pores of the wood. This would cause a biased error due to the volume of the paraffin film. Foor the purposes of this study the error was assumed to be negligible. The specific gravity was then computed using water-displaced volume and ovendry weight.

Rings per inch determinations were made by a count of rings per one-half inch. This figure was increased by a factor of two to give rings per inch.

At this point in the sampling it was apparent that there was very little correlation between the actual moisture content of the coniferous species selected and the electric moisture meter readings. In an attempt to establish some relation between the instrument readings and the actual moisture content percentage the universe was shifted to include one species of hardwood. Black cottonwood (*Populus trichocarpa* Torrey & Gray) was selected because it was readily available and the sap contains few organic solids such as pitch which might affect the conductivity.

The method of sampling described for the grand fir and lodgepole pine was also used for black cottonwood to give results which might be compared. No detectable difference in results was established between the conifers and the hardwood.

Analysis of Data

After the data was collected and arranged in a tabular form, (see Appendix, Tables I and II) scatter diagrams were plotted to determine any trend in the data. The scatter diagrams were plotted with both actual moisture content and electric moisture meter readings acting as the independent variable. The horizontal axis indicates the independent variable. From these diagrams, (see Appendix, Figures 19 and 20) it is apparent that there is no correlation between the actual moisture content percentage and the instrument readings because of the dispersion of the instrument readings over such a wide range. In an attempt to determine whether this dispersion was due to species a separate scatter diagram for grand fir was plotted with the same result. Another scatter diagram was plotted in an attempt to show a relation between specific gravity and actual moisture content. This diagram shows some correlation which would be a straight horizontal line. This relation has no value to this study. The scatter diagram of specific gravity over electric moisture meter readings shows no correlation.

All this lack of correlation shows that there must be variables which we

Table 1.—COMPARISON OF ELECTRIC AND OVENDRY MOISTURE CONTENTS

Tree No.	Species	D.B.H.	Height of sample	Sample number	Electric moisture content	Oven-dry moisture content	Specific gravity	Rings /inch
N1	grand fir		4.5'	N1	42	138.1	.519	16
				N2	28	109.4	.474	12
				N3	30	75.1	.529	40
				N4	30	58.7	.423	52
N1	grand fir		8'	N5	32	168.1	.421	21
				N6	30	196.5	.326	13
				N7	28	92.0	.430	22
				N8	40	105.1	**	**
N2	ponderosa pine*			N9	26	59.0	.375	16
				N10	26	45.8	.392	**
				N11	25	49.5	.412	**
				N12	29	77.6	.364	**
				N13	36	**	**	**
N3	western larch*			N14	26	100.0	.331	64
				N15	23	36.0	.425	26
				N16	23	35.2	.417	21
				N17	26	39.5	.430	17
				N18	27	40.0	.417	13
				N19	25	42.8	.452	13
N4	Douglas-fir*			N20	27	56.0	.350	28
				N21	27	73.4	.391	28
				N22	22	41.6	.401	**
				N23	21	30.0	.450	28
				N24	21	30.7	.447	20
				N25	20	32.4	.461	12

*Samples taken from down timber.
**Data missing.

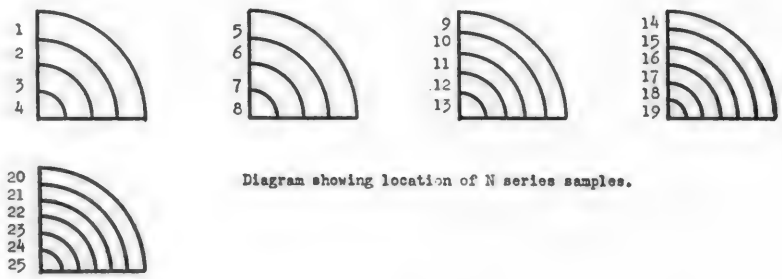


Diagram showing location of N series samples.

Table 2.—COMPARISON OF ELECTRIC AND OVENDRY MOISTURE CONTENTS

Tree	Species	D.B.H.	Height of sample	Sample number	Electric moisture content	Oven-dry moisture content	Specific gravity	Rings /inch
5	lodgepole pine	5"	10'	81	36	116.0	.566	22
				82	30	98.3	.529	17
				83	28	36.2	.417	8
				84	50	142.5	.479	28
				85	32	67.0	.414	14
5	lodgepole pine		20'	86	28	36.4	.384	6
				87	45	118.9	.532	20
				88	38	120.0	.458	16
				89	36	37.5	.353	8
				90	50	144.0	.464	20
				91	36	86.0	.424	11
6	lodgepole pine	5"	4.5'	92	36	128.0	.440	30
				93	30	53.5	.429	16
				94	28	35.5	.422	7
				95	45	97.0	.462	45
				96	30	52.0	.398	22
				97	26	35.1	.380	8
6	lodgepole pine		10'	98	40	110.0	.423	18
				99	30	176.0	.379	12
				100	23	78.0	.344	10
				101	40	115.0	.418	21
				102	30	48.6	.377	12
				103	25	35.1	.368	4
7	black cottonwood	8"	2'	104	50	205.0	.346	12
				105	47	156.0	.394	6
				106	65+	197.5	.374	5
				107	65+	176.4	.396	8
				108	60	193.1	.374	13
				109	50	148.7	.406	6
				110	65+	197.0	.390	6
				111	65+	152.1	.436	4
7	black cottonwood		4.5'	112	50	224.0	.305	12
				113	45	168.0	.370	4
				114	65+	188.1	.365	5
				115	65+	159.4	.440	6
				116	55	192.0	.356	8
				117	60	148.0	.403	10
				118	65+	197.6	.373	4
				119	65+	148.8	.457	4

Table 2.—(Continued)

Tree No.	Species	D.B.H.	Height of sample	Sample number	Electric moisture content	Oven-dry moisture content	Specific gravity	Rings /inch
3	grand fir	8"	4.5'	1	44	119.0	.496	10
				2	55	81.7	.441	9
				3	70	137.7	.475	36
				4	75	257.0	.390	16
				5	45	91.6	.573	14
				6	61	55.1	.597	12
				7	67	99.1	.487	14
				8	65	81.8	.338	12
3	grand fir		10'	9	50	227.0	.351	12
				10	50	174.6	.358	7
				11	55	53.5	.400	8
				12	70	90.3	.339	14
				13	45	231.0	.364	14
				14	70	81.4	.349	10
				15	75	108.2	.353	21
3	grand fir			16	65	77.9	.381	16
			20'	17	45	106.3	.453	44
				18	36	37.3	.686	17
				19	36	39.7	.400	26
				20	55	142.4	.425	24
				21	45	47.1	.380	16
				22	28	36.2	.352	16
2	grand fir	9"	4.5'	23	45	205.4	.359	20
				24	45	61.6	.338	19
				25	55	64.0	.357	16
				26	50	61.1	.394	14
				27	45	239.0	.351	14
				28	45	59.1	.376	15
				29	60	85.3	.351	12
				30	45	84.7	.378	14
2	grand fir		10'	31	40	151.0	.476	8
				32	55	94.9	.454	16
				33	50	42.6	.369	14
				34	35	42.4	.394	10
				35	38	193.0	.395	30
				36	65	93.4	.406	16
				37	65	68.2	.355	13
				38	50	61.7	.410	12
1	grand fir	7"	4.5'	39	65	144.0	.458	16
				40	50	47.7	.417	16
				41	38	40.4	.439	26
1	grand fir	7"	4.5'	42	60	58.0	.521	28
				43	65	159.4	.450	18
				44	43	59.4	.411	18
				45	40	40.2	.410	18
				46	45	58.4	.596	16
1	grand fir		10'	47	42	65.4	.372	32
				48	60	61.6	.369	14
				49	45	48.0	.329	14
				50	50	146.2	.435	14
				51	55	51.8	.321	11
				52	60	48.9	.290	12
4	lodgepole pine	7"	4.5'	53	50	142.0	.483	28
				54	34	72.6	.444	20
				55	24	34.6	.464	10
				56	29	36.0	.490	9
				57	62	114.0	.508	18
				58	34	108.0	.480	16
				59	35	54.1	.469	11
				60	26	35.5	.463	7
4	lodgepole pine		10'	61	45	110.0	.502	28
				62	30	97.6	.494	16
				63	23	31.5	.429	10
				64	28	34.1	.427	6
				65	47	130.0	.449	28
				66	34	63.5	.461	12
				67	23	33.5	.394	10
				68	28	34.7	.402	7
4	lodgepole pine		20'	69	45	112.0	.475	21
				70	40	136.0	.443	8
				71	27	36.0	.581	8
				72	30	152.0	.482	16
				73	40	166.2	.407	11
				74	30	53.0	.465	7
5	lodgepole pine	5"	4.5'	75	50	95.0	.668	20
				76	38	91.0	.521	24
				77	34	40.4	.448	10
				78	50	103.0	.458	24
				79	27	97.6	.667	17
				80	60	37.0	.481	9

did not recognize that affect the conductivity of wet wood.

Because the scatter diagrams showed so little correlation no attempt was made to subject the data to statistical analysis. It is apparent from Figure 19 that the coefficient of correlation would be in the neighborhood of zero.

Conclusions

The main conclusion to be drawn from the preceding analysis is that this particular principle and type of moisture meter is unsuitable for measuring the moisture content of wood above the fiber saturation point. The reasons for the failure of this instrument are unknown, however, it is doubtful if any electric moisture meter (resistance or conductance) can be used with accuracy in green or extremely wet wood. At the start of the test we expected to find no close agreement between meter readings and ovendry moisture contents above 30 percent, due to the electrical properties of wood. We had hoped, however, to find that the meter would give an indication of the relative magnitude of moisture content above 30 percent. The results did not bear this out except in a very general way. Our calibration attempt was not successful.

Even though the results are negative in character, the data gives the following positive conclusions:

Referring to the tables and diagrams, it can be seen that moisture content varies considerably with the position of the sample in the tree, with respect to the pith. Grand fir and lodgepole pine of the size tested have, in general, wet wood on the outside becoming progressively drier towards the pith. In the case of black cottonwood the opposite is the case, as the wood is wettest in the center, becoming progressively drier towards the surface.

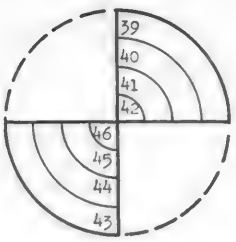
Reference to the tables and diagrams will also show that the height of the sample within the tree has no effect on the actual moisture content of the sample, position radially from the pith being held constant. The wide range of values for moisture content emphasizes this point.

Specific gravity has some relation to the actual moisture content. This is probably due to the percent of pore space that can be occupied by free water, and the higher specific gravity due to extractives found within the wood. The relation of specific gravity to actual moisture content is not drawn clearly by this limited number of samples.

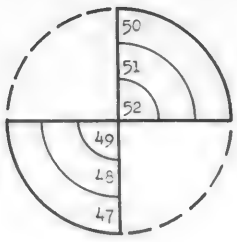
From the scatter diagram, Fig. 19, it is evident that for any instrument reading of over forty percent, the only conclusion that can be positively drawn, is that the wood is wet. It may vary from 40 to 190 percent actual moisture content. For an electric moisture meter reading of twenty-five the actual moisture content should be within fifty percent of this value.

By a simple calculation it can be shown that many of the sample blocks would sink. The values for specific gravity in Tables I and II cannot be used for this calculation because they are based on ovendry weight and ovendry volume which would not give the correct expression for unoccupied volume of the wood. Referring to the *Wood Handbook*[1] for average values for specific gravity the calculation can

[1] Forest Products Laboratory, Forest Service, *Wood Handbook*. U.S.D.A. 1935.



Height 4½ feet



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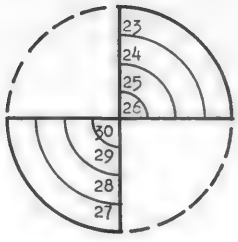

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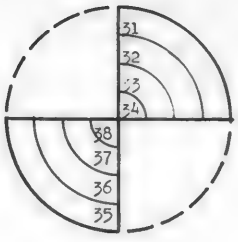


Height 10 feet

Figures 2–5.—Trees one and two, showing location of individual samples.

be made to determine the moisture content at which a wood will sink.

Weight of cubic foot of water x specific gravity of wood = weight of cubic foot of wood.

62.4 x .36 = 22.5 lbs. per cu. ft.

Then

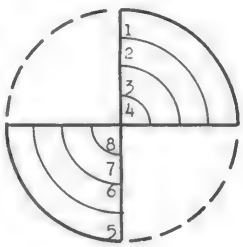
$$\frac{(\textit{Weight of cu. ft. of water} - \textit{wt. of cu. ft. of wood})}{\text{weight of cu. ft. of wood}} \times 100 = \text{moisture content percent at which wood will sink.}$$

$$\frac{(62.4 - 22.5)}{22.5} \times 100 = 170\%$$

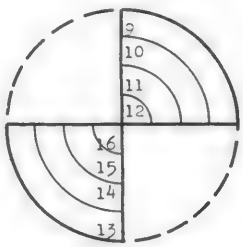
Referring to Table II, it is seen that no less than nine samples would have sunk in water. Going through the same calculations for lodgepole pine and black cottonwood, it is evident that only two samples of lodgepole pine would have sunk while only one sample of black cottonwood would have sunk.

Since there was no apparent difference of correlation between black cottonwood and the conifers, the variability of the readings is not likely to be due to the presence or absence of organic solids, such as pitch or resin in the conifers.

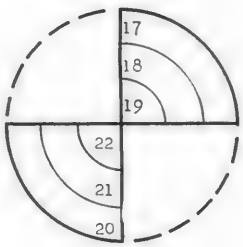
With the lack of correlation existing between the actual moisture content and electric moisture meter readings, it is apparently not feasible to use this type of moisture meter to determine the moisture contents of living trees. Perhaps a method using the moisture contents of increment borings could be used. A method such as this would eliminate all variables which affect instruments of the electric type.



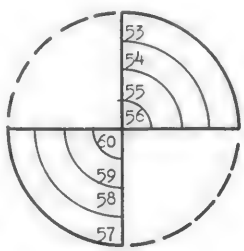
Height 4½ feet



Height 10 feet



Height 20 feet



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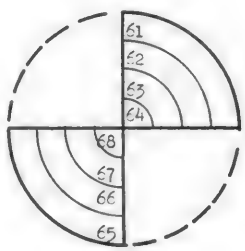
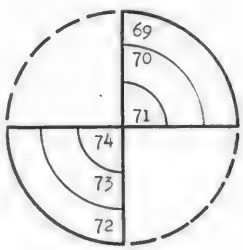
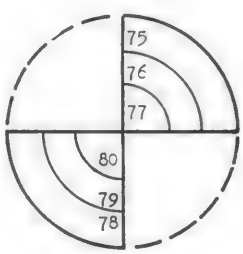


Height 10 feet

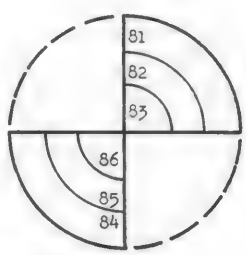


Height 20 feet

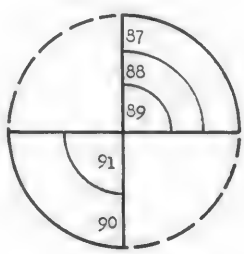
Figures 6–11.—Tree four, showing location of individual samples.



Height 4½ feet

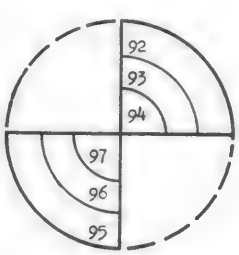


Height 10 feet

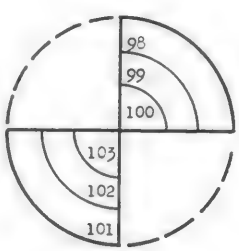


Height 20 feet

Figures 12–14.—Tree six, showing location of individual samples.

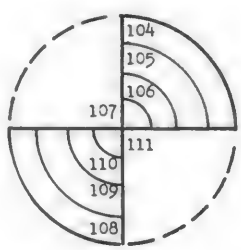


Height 4½ feet

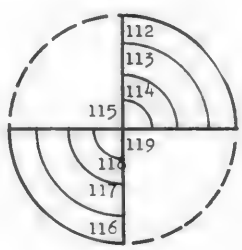


Height 10 feet

Figures 15, 16.—Tree six, showing location of indivdual samples.



Height 2 feet



Height 4½ feet

Figures 17, 18.—Tree seven, showing location of individual samples.

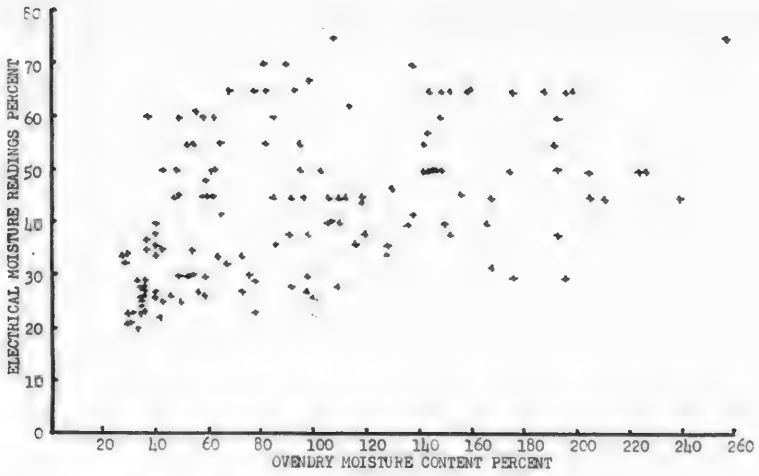


Figure 19.—The relation between ovendry and electric moisture contents.

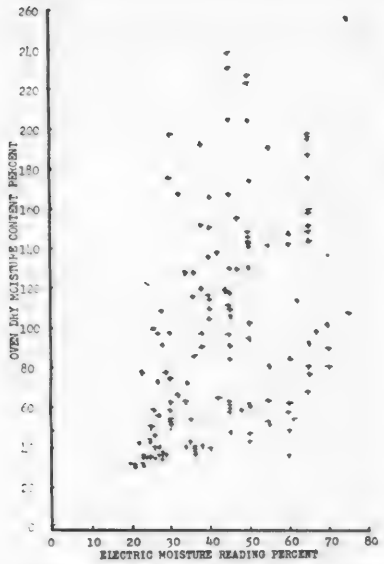


Figure 20.—The relation between electric and ovendry moisture contents.

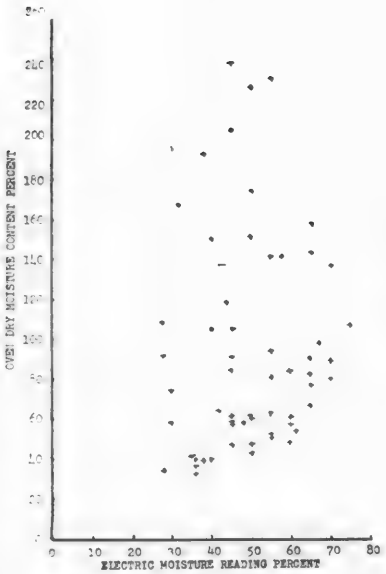


Figure 21.—The relation between electric and ovendry moisture contents for grand fir.

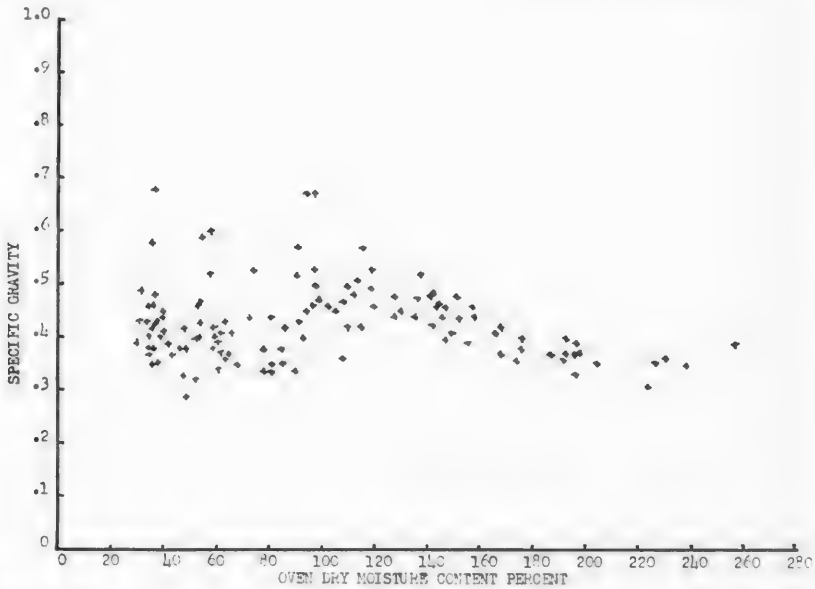


Figure 22.—The relation between ovendry moisture content and specific gravity.

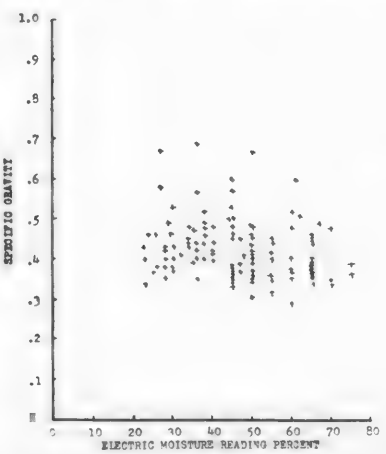


Figure 23.—Relation between electric moisture content and specific gravity.

Gluing Hardboard with Protein Adhesives[1]

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In general, properties of low or high temperature curing, good gap filling characteristics, glue-line alkalinity, fairly low cost, relatively low sensitivity to operating variables, and good adhesion to all grades and types of hardboard recommend protein adhesives for gluing hardboard in many applications.

THE RAPID GROWTH of the hardboard industry is coincidental with a very rapid growth of many allied industries involved in the use of hardboard. Although a number of uses for hardboard have been merely replacements of other building materials, its use in the fabrication of many new products by gluing processes is also important. As this paper deals with gluing hardboard with one specific type of adhesive, that being protein glues, the industries and end products herein discussed will be those in which a gluing operation with this adhesive type is used.

Protein adhesives to be discussed fall into the following classifications: soya, blood, soya-blood blend, casein and soya-casein blend glues. Each one has some characteristics that make it unique, and properties that determine its choice for a specific operation.

Industries, End Products and Conditions of Use

Door Industry: The gluing of hardboard directly to a hollow-core wood frame in the production of interior grade flush doors is probably one of the most important protein gluing operations for hardboard at this time. When this gluing is done with protein adhesive the operation is predominately a cold press, no-clamp process with casein, casein blend and soya glues being used. There are also a number of operations in which these flush doors are hot pressed; but in general, a protein glue, because of its extremely high water content, is not satisfactory for this type of operation.

Plywood Industry: The gluing of hardboard to veneer cross banding or cores in the production of interior grade plyron is also an important gluing operation. This again is predominately a cold press, no-clamp process where soya type glues are used. A good deal of interior grade plyron is also produced by hot pressing. For this type of operation soya-blood blend and straight blood adhesives do a very satisfactory bonding job and fit well into normal plywood operations.

Also in the plywood industry, the gluing of one hardboard face to a plywood construction, then striating the hardboard to produce a specialty plywood panel with a decorative surface is a cold press, no-clamp operation using a soya glue.

There are also specialty grades of plywood produced for various packaging containers in which hardboard is glued to one surface of a plywood panel. Here again no-clamp, cold press is done.

Hardboard is also glued to plywood to form a base for thin decorative hardwood veneer or high pressure decorative laminating materials. Hardboard works very well for this type of product since there is no show-through of grain as is often the case when coarse-grained wood is used as the base material. When a protein glue is used for this operation it is chiefly in a no-clamp, cold press process. If the hardwood veneer or high pressure laminate is to be hot pressed onto this panel, this interior type of bond is not satisfactory as the secondary hot pressing will generally cause delamination.

Furniture Industry: In the manufacturing of many grades of furniture, hardboard is laminated to wood core or other backing materials for producing table tops, cabinets and other miscellaneous furniture items. For this type of operation, casein glues are generally used in a cold press process in which the product is clamped to give sufficient time for the adhesive bond to cure.

Hardboard Fabricators and Store Fixtures Industry: Hardboard is laminated to wooden core members to manufacture a number of various types of industrial shelving, counter tops, and other display fixtures. Here again casein glues are used in a cold setting type of operation in which the material is clamped for a period of time to cure the adhesive bond.

Hardboard Industry: The hardboard industry itself does considerable laminating to form thick hardboard panels. Using a soya type glue this product is fabricated by cold pressing, using the normal plywood no-clamp operation.

Other Miscellaneous Industries: A great deal of hardboard is also used where it is glued in place. In other words, the hardboard is used as is and is glued into various types of paneling, furniture and other items in home work, cabinet shop and home building where the hardboard is used as a replacement for plywood and other wooden members. The only type of protein adhesive that is important for this operation is cold setting casein glue with good gap filling qualities.

There are other industries in which hardboard is glued, but the above mentioned ones are those in which the protein type of glue is most important.

Comparison of Protein Glues with Competitive Types as to Costs

The glue-line costs of the various types of protein adhesives vary from $2.70 to $18.00 per thousand square feet of double glue-line. Listed below are the approximate costs per thousand square feet of double glue-line of each protein glue type:

Straight soy glue	$ 3.80
Soy-blood blend glues for hot pressing	2.70 to 3.00
Straight blood glue	3.50
Soy-casein blend glues	9.00 to 10.00
Straight casein glues	12.00 to 18.00

To compare these with other adhesive types, based on the same calculations, the interior phenolic resins run from $3.00 to $3.50, exterior phenolic resins from $5.00 to $6.50, urea resins from $8.00 to $12.00 depending on the amount and type of extension, resorcinol resins from $50.00 to $65.00 per thousand and polyvinyl glues from $30.00 to $35.00 per thousand. These glue costs may not agree with some other calculations, but they can be used for comparative purposes as all calculations were made on the same basis using recommended spread for 1/8 in. core plus 25% waste.

[1] Presented at FPRS Pacific Northwest Section, Hardboard Division, meeting, May 17, 1954, at Aberdeen, Washington.

Comparison of Protein Glues With Other Type as to Method of Preparation and Application

Mixing procedure for different types of protein glues vary considerably from a relatively complicated and difficult mixing procedure to a very simple straight forward water addition. The straight soya, soya-blood blend, straight blood glues and some of the soya-casein blend glues require the use of various chemicals to be added at time of mixing, with very great care necessary to get the right properties in the final glue. The mixing period, as well as the quantity of the additives must be closely controlled.

For the straight casein glues the mixing procedure is much simpler in that only water is added to the dry glue; this is then mixed together and allowed to set for a short period of time. The mix is then completed and the resulting glue is smooth and ready to use.

Protein glues may be spread with the standard type of glue spreading equipment although it may be necessary to have special roll groovings to obtain the relatively high spreads that are required for some types.

Comparison of Protein Glues With Other Types as to Glue-Line Properties

Most protein glues if properly used will result in a 10-cycle glue-bond in hardboard to Douglas Fir applications. This is the 10-cycle test as used by the D.F.P.A. The glue-bond must withstand 10-cycles of alternately soaking for 4 hours in water at room temperature and drying for 20 hours at temperatures less than 100°F. Protein glue-bonds have good gap filling properties which are important with thick and thin core, rough core or when deep screen backing is present on hardboard. They exhibit good adhesion to surfaces such as hardboard and the resulting bonds have good dry strength and good water resistance; however, these glues will not pass the boil test for exterior performance. It has been found that hot press soya-blood blends and straight blood glues have the greatest water resistance of the protein glues with casein next in order. It has been found, however, that the water resistant quality of the bond is determined by the type of gluing job done as well as by the water resistance of the glue itself.

The attached tables show 10-cycle performance as well as the dry shear for several protein adhesives and various hardboard types and grades, including treated bonds. Table I covers standard and Table II treated grade. Several of the adhesives tested are not commercially used, but were included to give a complete coverage of the protein glue type.

Protein glues are susceptible to fungus attack under conditions conducive to the growth of mold. If these conditions are to be encountered by the end product, it is advisable to add a mold inhibiting material to the glue at time of mixing. There are a number of these mold inhibiting materials available that are quite satisfactory, and when a hot press protein glue is used it has been found that a proportion of phenolic resin added to the glue mix will give good mold inhibiting properties.

Protein glues seem to do a particularly good job in gluing hardboard as they have the so-called "alkaline bite" that will get a good hold on the hardboard even with the oily dense surface of many unsanded treated grades of hardboard.

Advantages and Disadvantages of Protein Glues

Many of the protein glues such as the straight soya, soya-blood, straight blood and even the soya-casein blends have a cost advantage over many other interior glues that can be used for this type of gluing operation. The casein glue is considerably higher in cost, but quite often is the only glue type that will do the desired type of bonding job.

Due to this low cost, soya glues, soya-blood and blood glues can be spread at relatively high ranges, therefore giving good gap filling qualities and also good assembly properties for various bonding operations. The casein and soya-casein glues have a distinct advantage in that they can be cold pressed at temperatures down to the freezing point where some of the other cold press resin glues do not perform well below 65°F.

Protein glues are often less sensitive to operating variables, such as moisture content and smoothness of the stock, spread control and pressing conditions. Although these glues will usually withstand more abuse than some of the other glue types, best results are not obtained unless the glue manufacturers recommendations are closely followed.

The protein glues also have a particular advantage in that they can satisfactorily bond unsanded, treated grades of hardboard as well as the many other grades.

The disadvantages are mainly in that the protein glues have more involved mixing procedures in general and that they have a limited water resistant bond as compared to some of the other adhesive materials. Another disadvantage is that the high water content of this type of adhesive often causes excessive dimensional strain and in some cases has caused excessive warpage. This, however, is generally related to the type of gluing procedure; and, if the glue manufacturers recommendations are followed as to spread control and assembly time, this problem can generally be handled without changing glue type.

Adhesive Components and the Relation of These Components to the Glue Bond

The basic component responsible for adhesion in this type of adhesive is, of course, the protein. In soya glues this protein is from the soya bean flour, in blood glues protein is from blood albumin, in casein glues the protein is from the curd of milk. As mentioned before, protein adhesives can include any one of the above proteins by themselves or in combinations with one another.

The other components of a protein glue, such as water, caustic soda, hydrated lime, silicate of soda, carbon bisulfide, mold inhibitors and anti-foam agents are used to convert this protein material into a usable glue and to improve such factors as bond strength, water resistance, viscosity, spreadability, pot life, foaminess and mold resistance. The adhesive manufacturer has determined the proper balance of these chemicals for best performance and, although they are at times varied to make special adjustments for some particular gluing operation, these components should not be altered.

The chemical action in the case of protein glues is the gellation of the protein molecules which is enhanced by certain chemicals in the glue mix such as lime. In the case of a casein glue, the end product of a cured glue-line is the very insoluble calcium caseinate. As for soya glues the action of protein is different and the resulting end product is not quite as insoluble as the calcium caseinate. The initial action responsible for the adhesion of a protein glue is physical rather than chemical and results from a rapid thickening of the glue as the water is absorbed into the wood or hardboard. This thickening action gives a pasting effect by which the materials to be glued are held tightly together until the actual gellation or cure of the protein takes place at a slower rate in the glue-line. This thickening action gives a protein glue its so-called no-clamp properties, where the pressure is applied for a given period of time, then is released and the pasting quality of the glue is sufficient to hold adequate contact for cure in storage.

Protein Adhesives Mixing and Handling Directions as Recommended Relating to Hardboard Gluing

Mixing: The mixing of protein adhesives varies considerably, but in general, soya, soya-blood blend, straight

Table I.—TEST RESULTS—GLUING STANDARD GRADES OF HARDBOARD TO FIR VENEER

Protein Glue	Pressing Method	Hardboard Surface	HARDBOARD TYPE A Dry Shr.	A 10 Cyc.	B Dry Shr.	B 10 Cyc.	C Dry Shr.	C 10 Cyc.	D Dry Shr.	D 10 Cyc.	E Dry Shr.	E 10 Cyc.
Soya	N.C.	Sm.	70- 98	100	45-100	100	84- 99	100	91- 99	100	110- 93	100
		Sc.	79- 82	100	73- 66	100						
Soya-Blood "A"	H.P.	Sm.	59-100	100	44-100	100	104-100	100	120-100	100	132-100	100
		Sc.	55- 95	100	71- 99	100						
Soya-Blood "B"	H.P.	Sm.	73-100	100	70- 87	100	86-100	100	123-100	100	131-100	100
		Sc.	61-100	100	92- 98	60*						
Blood	H.P.	Sm.	88-100	100	87-100	100	119-100	100	129-100	100	139-100	100
		Sc.	100- 90	100	98- 73	100						
Soya-Casein "A"	N.C.	Sm.	91- 99	80	68-100	90	127- 97	100	125- 98	90	121- 98	70
		Sc.										
Soya Casein "B"	N.C.	Sm.	86- 79	100	65- 95	100	118- 97	100	123- 90	80	139- 99	100
		Sc.	89- 82	80	106- 73	90						
Casein "A"	C	Sm.	87-100	100	63-100	100	110- 95	100	138- 87	70	94-100	80
		Sc.	102-100	100	79-100	100						
Casein "B"	C	Sm.	101-100	100	63-100	100	83- 99	100	136- 98	80	128-100	70
		Sc.	98- 99	100	77-100	95						

Key: Pressing Method
N.C. = no clamp (cold press)
C. = clamp (cold press)
H.P. = Hot Press
Hardboard Surface
Sm = Smooth (glued side) Pressed smooth or screenback planed off.
Sc = Screened (glued side)
*Delamination within hardboard itself close to glue-line.

Test Results:
Dry Shr.—Dry shear test, shear strength in p.s.i.—% fibre failure.
10 Cyc.—10 cycle test, % of specimens passing 10 cycles.

Protein Glue	Pressing Method	Hardboard Surface	F Dry Shr.	F 10 Cyc.	G Dry Shr.	G 10 Cyc.	H Dry Shr.	H 10 Cyc.	I Dry Shr.	I 10 Cyc.
Soya	N.C.	Sm.			79- 99	100			85-100	92
		Sc.	92-100	70*	-------	---	78-100	60*	78-100	100
Soya-Blood "A"	H.P.	Sm.	-------	---	112-100	100	-------	---	91- 98	100
		Sc.	119- 98	100	-------	---	50- 98	100	67- 96	100
Soya-Blood "B"	H.P.	Sm.	-------	---	111-100	100	---	---	83- 84	100
		Sc.	113-100	100	-------	---	63- 90	100	-------	---
Blood	H.P.	Sm.	-------	---	-------	---	---	---	-------	---
		Sc.	79- 97	75	-------	---	89- 93	100	75- 70	80
Soya Casein "A"	N.C.	Sm.	-------	---	112- 75	100	-------	---	-------	---
		Sc.	105- 97	100	-------	---	72- 90	70	88- 71	80
Soya Casein "B"	N.C.	Sm.	-------	---	-------	---	-------	---	-------	---
		Sc.	133-100	100	-------	---	104- 94	100	118-100	50
Casein "A"	C	Sm.	-------	---	108- 97	93	-------	---	160-100	100
		Sc.	121-100	100	-------	---	116- 99	65*	88- 99	80
Casein "B"	C	Sm	-------	---	111- 96	100	-------	---	-------	---
		Sc.	110- 98	100	-------	---	112- 99	75*	103- 99	100

Note: Construction tested was 3-ply plyron using 3/8" fir veneer core and 1/8" or 1/10" hardboard faces. Shear specimens were tested according to standard plywood shear test on a pendulum type machine at an approximate loading rate of 800 lbs. per minute.

Table II.—TEST RESULTS—GLUING TEMPERED GRADES OF HARDBOARD TO FIR VENEER

Protein Glue	Pressing Method	Hardboard Surface	HARDBOARD TYPE A Dry Shr.	A 10 Cyc.	B Dry Shr.	B 10 Cyc.	C Dry Shr.	C 10 Cyc.	D Dry Shr.	D 10 Cyc.	E Dry Shr.	E 10 Cyc.
Soya	N.C.	Sm.	103-100	100	117- 99	85	143- 86	100	-------	---	-------	---
		Sc.	- - -	-	- -	- -	--- - -	--	158- 70	100	130- 97	100
Soya-Blood "A"	H.P.	Sm.	112- 99	100	97- 99	100	135- 93	100	-------	---	-------	---
		Sc.	-------	---	-------	---	146- 50	100	57- 95	100	126- 99	100
Soya-Blood "B"	H.P.	Sm.	81- 90	80	95-100	100	148- 98	100	-------	---	-------	---
		Sc.	-------	---	-------	---	125- 75	70	129- 77	100	148-100	100
Blood	H.P.	Sm.	95-100	100	98-100	100	155- 95	100	77- 5	75	72- 93	45
		Sc.	-	--	- -	-	144 99	100	---- -	-	- -	- -
Soya-Casein "A"	N.C.	Sm.	-	- -	- - -	- -	134- 57	60	-------	---	-------	---
		Sc.	- -	- -	- -	- -	- -	--	67- 28	40	132- 87	75
Soya Casein "B"	N.C.	Sm.	88 100	75	103 97	80	139 - 83	- -	-------	---	-------	---
		Sc.	-	-	- -	-	------	---	141- 47	50	81- 54	45
Casein "A"	C	Sm.	133-100	100	118 100	100	170-100	100	-------	---	-------	---
		Sc.	--	-	- - -		192-100	100	144- 97	100	170- 97	90
Casein "B"	C	Sm.	- - -	-	131 100	100	174-100	100	-------	---	-------	---
		Sc.	- -			--	174-100	80	113- 46	65	161- 87	75

Note: None of the boards were sanded prior to gluing. See other notations and Key under Table I.

blood, and soya-casein blend glues require the addition of a number of other components which must be carefully added for best mixing and handling. It is often necessary for a glue manufacturer to adjust the glue mix for best operating characteristics on some specific spreading equipment and for some specific gluing operation. It also may be necessary to carefully adjust the glue viscosity so that it can be best handled or for best penetration into hardboard surfaces. In some cases the alkalinity of the mix may be adjusted slightly for optimum results on certain types of hardboard material.

Spread: In some cases glue spreads obtained are regulated by the type of equipment which is present. This, however, is just an expedient; and for best

results the spread should be set for optimum operation even if a change or modification of the spreader is necessary to obtain this spread. The adjustment of the optimum spread is related to the porosity and roughness of the core stock and to the type of hardboard being glued. The spread chosen is also related to the final end product being desired. In most cases spreads used for gluing hardboard are in line with those used for that particular glue type when gluing plywood, furniture or in other fabricating processes. In some cases it may be necessary to keep spreads at a minimum for hot press work where excessive moisture may cause blistering. It may also be important to keep spreads at the low end of the range to minimize grain raise of the core, or the showing through of a door core as in the case of flush doors. Again, spreads often must be kept at a minimum to insure the lowest possible amount of moisture being incorporated into the glue-line for reduction of warpage tendency and to minimize glue-line stress. In general, spreads must be adjusted to give proper glue-bond without the waste of glue.

Assembly Time: The assembly time of the glued construction prior to its being pressed is often determined by the type of operation; in the case of protein glues the spreads are generally on the high range and therefore assembly times can be longer than for some other adhesive types. However, careful consideration of assembly time must be given because if the maximum permissible assembly time is exceeded the glue will dry out to such an extent that, when pressure is applied, there is not sufficient flow to cause penetration into the other surface of the construction. It is also important to control assembly time where additional penetration is needed; in this case a longer minimum closed assembly time under a heavy caulboard may be necessary before the construction is put under pressure. These conditions are very important and must be checked closely for each particular gluing operation as each of the protein glues discussed has a different assembly time range and each particular gluing operation has a particular assembly time pattern. In general, the gluing of the less dense standard grades of hardboard is not as critical to assembly time as many of the treated and more dense grades of boards.

Pressure: The recommended pressure for gluing hardboard is again very critical as pressure necessary for bonding the adhesive is fairly relative. If the surfaces are perfectly smooth good contact is all that is necessary. In the case of most gluing operations, however, core roughness, thick and thinness of the core, and other manufacturing variables require the use of sufficient pressure to guarantee that contact is achieved over the entire gluing area. Depending on the particular application, from 75 to 175 p.s.i. actual pressure on the contact area is usually sufficient. In the case of a hollow-core door gluing operation excessive pressure may cause show through of the core construction and may cause excessive warpage. High pressure may also cause excessive squeeze-out of the glue or the pushing of glue away from areas where it is needed. It is therefore necessary to adjust the pressure for each particular gluing operation and for each adhesive being used.

Pressing Time: The press times necessary for gluing hardboard are also governed by the type of operation. In general, for a particular adhesive type, the press times are very similar to those used in most gluing operations where wood of the same thickness is used instead of hardboard. For a no-clamp operation using a protein glue, from 10 to 20 minutes press time is usually sufficient for either flush doors or plyron. The actual press time depends on the particular adhesive used, and for the straight soya-bean glue the longer press time is usually necessary. It has been found that a certain type of soya-casein blend glue works extremely well for no-clamp pressing of flush doors. Here the press time is somewhat shorter and 10 minutes has been found to be entirely satisfactory.

In hot pressing, the press time for plyron construction is generally about the same as for plywood; however, it may be necessary to add up to 30 seconds press time to constructions of identical thickness to allow for the slower heat transfer in some of the denser hardboards.

Laboratory tests made with thermocouples placed in the glue-line indicate the following relationships: Using a 1/10 in. hardboard face in place of 1/10 in. fir veneer it is necessary to add 15 seconds to the press time. When 1/8 in. hardboard replaces 1/8 in. fir veneer it is necessary to add 30 seconds to the press time. The above tests were made with hardboard having a specific gravity of approximately 1.0.

Limitations, Problems and Precautions in Using Protein Adhesives for Gluing Hardboard

Staining: Protein glues, because of their alkalinity, will stain wood or wood base materials such as hardboard. Therefore, care should be taken by the lay up crew so that glue is not wiped or slopped onto the visible hardboard surfaces. Staining often results in the appearance of a wide glue-line, and when the edge of a construction is visible in the end product, this may also be a problem. Hardboard in general is thick enough that there is no stain-through of the glue from the glue-line to the surface as is the case with some thin surface materials such as decorative hardwood veneers.

Shallow Bond: There are applications in which protein glues have not given a good bond to hardboard from the standpoint of strength and depth of the bond. In some cases the panel has delaminated shortly after the gluing operation. An examination of the failure has shown it to be an internal delamination of the hardboard very near the glue-line rather than any failure of the glue bond itself. However, the proximity of the failure to the glue-line and the fact that it sometimes occurs without the application of external stress, indicates that some property of the glue is involved.

So far this problem has arisen only with the standard grades of hardboard, and seems to be due to a combination of several factors. The relatively high water content of protein glues results in greater swelling stresses at the glue-line during and after the gluing operation. These stresses may be sufficient to fail the hardboard at a point where it has been weakened by absorption of water and/or the relatively high alkalinity of protein glue. Also some hardboards seem to have a dense skin effect at the surface with an underlying plane of weak bond strength. Lack of glue penetration through this weak area results in delamination at that point when stress is applied. Sanding the dense surface before gluing has proved to be remedial in this case. Otherwise this problem can usually be eliminated by the use of a modified glue mix or by changing to some other adhesive, either within the protein grade or some other glue type.

Precautions against Dermatitis: The reaction of some adhesives on human skin is always a problem, but in the case of protein adhesives it is no worse than any other material of similar alkalinity, as there is generally no dermatitis effect from the protein itself.

Effects of Hardboard Variables on Protein Glues and Gluing Recommendations

Density: Within the range of specific gravity normally encountered in gluing hardboard, say 0.85 to 1.20, density does not have a significant effect on the overall good performance of protein glues, based on laboratory and field results available to date. In certain cases it may be advisable to use thinner glue mix and a longer minimum closed assembly time to insure adequate glue

penetration into some very dense hardboard surfaces.

Resin Content: Within the range of resin contents normally used in hardboard (1/2 to 5%) this variable has apparently no significant effect on the performance of protein glue-lines. Shear strengths are higher on the higher resin content boards but percentage fiber failure remains about the same. The soak test, based on 10-cycle performance of various board types, does not seem to show any noticeable difference between boards made at various resin contents. This applies to protein glues only and, probably due to a relatively high alkalinity, this type of adhesive has the characteristic of biting deeply into even the dense, high resin content boards.

Moisture Content: Protein glues are less sensitive to moisture content at times of pressing than most other glue types and are not significantly affected by this variable within the limits encountered in humidified hardboards. With the hot press soya-blood blend or straight blood glues it may be necessary to reduce the press temperature and increase the press time if the hardboard has picked up an excessive amount of moisture in storage. As protein glues contain a large amount of moisture in the glue mix, any blistering hazard that may be present because of moisture content of the hardboard is even further aggravated.

Treating: In the following discussion the terms "treated" and "tempered" are synonymous and refer to the treatment of hardboard with various types of polymerizing oils followed by a baking process to increase the water and strength properties of the board.

One of the advantages of protein type glues over many other types for gluing hardboard is their ability to satisfactorily glue unsanded treated boards. In fact, their performance on tempered boards is generally about equal to that on standard boards. Shear strengths are higher for treated boards because of the greater strength of the board itself, while fiber failures remain about the same as for standard grades.

Surfaces: (Plate, Screen, Planed, Sanded, etc.) Protein glues in general will give satisfactory bonds to most hardboards irrespective of the surface type. However, boards having deep screening marks on the back require planing or sanding to a reasonably flat surface to insure satisfactory bond. Where the screening is very deep there is a relatively small amount of contact area that can possibly be bonded. Where screening is not very deep, a fairly heavy spread of a thick protein glue mix will usually have sufficient gap-filling properties to give an adequate bond. In any event, planing or sanding improves the glueability of hardboard, although it may not be required for protein glues in a number of gluing operations. The nature of the surface as it affects glueability must be considered even though it is known that protein glues will usually do a satisfactory bonding job on surfaces without excessive screen depth. This bond may not be sufficient to furnish the type of end product desired. When gluing the smooth side of some hardboards it is desirable to lightly sand the surface to assist in adequate glue penetration through the high density skin on the surface. Most protein glues have sufficient "bite" to penetrate these dense surfaces, but a stronger bond with deeper fiber failure will result when the glue bond is tested if the surface has been sanded prior to gluing. This applies to the smooth side of some standard boards as well as treated boards.

Method of Manufacture: According to laboratory tests and field experience accumulated to date, the various basic methods of hardboard manufacture do not significantly affect the performance of protein glues in gluing the hardboard produced. The internal bond strength of the various boards may differ, but in all cases the glue-bond exceeds this strength to such a degree that very nearly 100% fiber failure in the board is obtained at time of testing the bond in dry shear. This is also the case in 10-cycle soak test where in most cases delaminations that do occur are due to improper gluing procedures or due to acutal delamination of the board itself. As mentioned before this delamination within the board itself is sometimes related to the type of glue used. However, most standard grades of hardboard, regardless of board manufacturing process, have exhibited this property at one time or another. Depending upon the application, it may be advisable to use a non-alkaline, low water content glue to eliminate this problem.

Conclusions

Protein glues, because of many desirable properties, lend themselves to the gluing of hardboard in a variety of operations. The cold press no-clamp feature of soya and soya-casein blend glues make it possible to produce interior grade plyron, flush doors, and other products without the necessity for expensive hot pressing equipment, complicated clamping procedures, or a heated plant in the winter time. On the other hand, soya-blood and blood glues make it possible to hot press hardboard using protein adhesives. If a cold press gluing operation requires clamping, soya and soya-casein blend glues can be used, but it is also possible to use a casein glue which offers the advantages of greater water resistance and more simplified mixing procedures.

In general, the properties of low or high temperature curing, good gap filling characteristics, glue-line alkalinity, fairly low cost, relatively low sensitivity to operating variables and good adhesion to all grades and types of hardboard result in the favored use of protein adhesives for gluing hardboard in many applications.

Table 1.—AVERAGE INCREASE IN MOISTURE CONTENT OF PAINTED AND UNPAINTED HARDBOARD TEST PANELS →

	Location	Applied to wall or loose	Painted or unpainted	Moisture content at start Percent	Average moisture content and condition of panels after the indicated number of days: 1 day M.C. Pct.	1 day Condition	4 days M.C. Pct.	4 days Condition	6 days M.C. Pct.	6 days Condition	15 days M.C. Pct.	15 days Condition	Number and size of test samples
A	Open warehouse	Applied(1)	painted	4.2	5.2	Flat	---	---	7.2	Buckled	7.5	Buckled	10–36 in. x 48 in
	Open warehouse	Applied(1)	unpainted	4.2	6.2	Buckled	---	---	---	Buckled	7.8	Buckled	10–36 in. x 48 in
	Open warehouse	Applied	painted	3.0	---	---	5.6	Flat	6.5	Buckled	---	---	10–36 in. x 48 in.
	Open warehouse	Applied	unpainted	3.0	---	---	6.0	Buckled	6.9	Buckled	---	---	10–36 in. x 48 in
B	Open warehouse	Loose	painted	0.0	---	---	8.4	---	9.2	---	---	---	4–20 in. x 24 in
	Open warehouse	Loose	unpainted	0.0	---	---	8.7	---	9.4	---	---	---	4–20 in. x 24 in
	Heated building	Loose	painted	0.0	---	---	5.5	---	5.6	---	---	---	4–20 in. x 24 in
	Heated building	Loose	unpainted	0.0	---	---	5.7	---	5.7	---	---	---	4–20 in. x 24 in.

(1) Nailed to studs with faces and edges exposed. Studs spaced 24 inches on center. Buckling between studs.
Note: (a) Days of part A and B do not coincide.
(b) Controls (19 pcs. 11 x 14 in. part A—20 pcs. 8 x 24 in. part B) were used to trace moisture content pattern of larger panels. This was not necessary for the loose panels. Control pieces were weighed at each noted specific time and when no further readings were necessary they were taken down and oven dried to a constant minimum weight. The respective moisture contents were then calculated. All control pieces were nailed on the wall similarly and adjacent to the larger panels and for weighings were taken down but replaced immediately.

Effect of Paint Sealer on Buckling Tendencies of Hardboard Paneling[1]

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A limited study was undertaken to explore the effect that pre-sealing might have on retarding the movement of moisture into hardboard panels so as to keep the boards as flat as possible. A one-coat latex emulsion sealer was applied to the face of hardboard panels prior to installation. The experimental panels were ¼-inch thick untreated hardboard having a specific gravity of 0.9.

MUCH HARDBOARD has been used to date as interior paneling in such places as recreation rooms, dens and bedrooms, where the equilibrium moisture content of the hardboard prior to and after installation has suffered little change. For these uses, buckling is of little concern provided the panels are properly humidified at the factory.

However, in new construction, especially in industrial buildings which are usually left open until after the paneling is installed, there may be moisture pickup both from the atmosphere and from other building materials. In such cases, just after installation hardboard paneling is often subject to high EMC conditions—and even though it may only be for a short time, these conditions would be high enough to cause unsightly outward bowing of the panels between studs. This abnormal shape may last even after the introduction of heat into the building. Certainly much hardboard has been used as paneling in new buildings with excellent results, but a few isolated cases of trouble do not help the general acceptance of hardboards in place of the more widely known plaster boards.

Experimental Procedure

A wall inside a warehouse, but next to a large opening, was used because the panels would be subject to outdoor fluctuations in relative humidity without being exposed. This would be similar to paneling an industrial building not yet closed in or heated. Relative humidity was 85–95 percent at 55° F.–65° F.

Sections were applied with only faces and some edges exposed. Edges were supported so that movement of one panel would not affect adjacent one. Panel sections were nailed to 2 x 4 in. studs spaced 24 in. apart rather than the more common 16 in. spacing in order to exaggerate results.

Painted and unpainted sections, and controls where necessary, were taken from same panels. Panels were painted either by brush, spray or roller, and an effort was made to give all sections under comparison the same uniform coat.

A low starting moisture content was often used in order to quicken results.

Buckling was observed visually. It was considered critical when panels buckled out 1½ in. from the plane of the wall. Obviously this system could not be accurate, but at least afforded a means of comparison.

Summary of Observations

Face-sealed or treated panels definitely exhibited less tendency to buckle between supports than non-treated panels, this difference becoming less significant, depending upon the time of exposure and the amount of moisture present.

When panels were exposed to humid conditions the M. C. of face-sealed boards rose, lagging at first, then almost simultaneously with non-treated boards. However, the sealed panels still did not buckle to the same degree as those not sealed.

Non-treated boards buckled at 2–3 percent M. C. increase whereas treated boards buckled at 3–4 percent M. C. increase. This might indicate that the paint film absorbs moisture, reducing the amount taken in by the fibres, or that the paint film binds the surface fibres together.

Over a 4 ft. width, 1/16 in. increase in linear measurement can produce unsightly-buckling (1½ in. out from plane of wall). Face-painted panels did not increase in linear measurement as much as unpainted boards during a specific time.

If conditions are such to raise the M. C. of hardboard paneling (one side exposed) enough to cause buckling, 24 hours is all that may be required. This indicates that much of the moisture lies on or near the surface of the panel.

When panels were closely stacked in a heated room with a low E. M. C. they tended to retain or slowly lose their original, though higher, M. C. at the time of stacking. Whereas, when the air was free to circulate on all sides, the loss of moisture was much faster.

Panels exposed on two sides logically picked up more moisture than those exposed only on one side. However, the face pick-up of moisture appeared to contribute most to the M. C. increase with resultant buckling. If this is always true, then the greater tendency of the face to pick up moisture could be combatted in two ways before boards are installed in humid locations.

(a) By pre-dampening *face* so as to reduce amount of water absorbed. Usually, nominal shrinkage if it takes place is not unsightly.

(b) By pre-sealing face with paint so as to restrict movement of vapour into the boards until humidity conditions become more favourable.

[1] Presented at meeting of the Forest Products Research Society, Pacific Northwest Section, Oct. 12, 1953, Seattle, Washington.

Table 2.—AVERAGE INCREASE IN MOISTURE CONTENT OF PAINTED AND UNPAINTED HARDBOARD TEST PANELS

	Applied to warehouse wall with faces and edges exposed			Closely stacked in a heated room		
Panel	0 days	1 day	13 days	13 days	19 days	21 days
Painted	0% M.C.	3.6%	6.3%	6.3%	6.1%	6.0%
Unpainted	0% M.C.	4.5%	6.5%	6.5%	6.1%	6.2%

19 pieces—11 x 14 in.
Panels were nailed on warehouse wall in similar position to Table 1 panels. After 13 days pieces were removed and placed closely stacked in a heated room at R.H. 55–65 percent at 70°F.

Some Fundamentals of High Frequency Gluing[1]

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Relates, in part, a wealth of personal experience of the author, a pioneer in this field. Points out fundamental "do's and don'ts" in procedures and applications, particularly in setting of glues. Helps answer initial questions for individuals considering installation or economics of r.f. gluing.

IN 1935, or thereabouts, Mr. George F. Russell and I became interested, more or less as a hobby, in the peculiar heating effects of radio frequency electromagnetic fields with especial emphasis directed toward dielectric heating in so called non-conductors of electricity such as wood.

It was not long before the concept of setting glues in relation to fabrication of wood panels, veneers, etc., intrigued us as well as others whose primary interest was wood and who were seeking improved methods for gluing wood. Early laboratory results were quite astonishing and the application to industry, exciting.

During the intervening twenty years the development and experience in r.f. heating has established certain procedures and applications, especially with relation to setting glues used in the fabrication of wood products.

Pressure and Clamping Devices

The heart of the entire process is the r.f. generator. On the other hand, without auxiliary equipment, such as a pressure means or clamp to hold the stock in juxtoposition while being glued, the generator alone would be quite useless. However, not just *any* pressure means may be used in conjunction with a given electrode system and a given generator, because the framework and component parts of the press are also a part of the radio circuit.

The fabrication of the press and mechanisms involved must be designed around the peculiar physics of the high frequency field of force and the particular mode desired to fit the load. Hence, mechanical expediency becomes secondary. For example, it is very essential that the electrical charges in the system be symmetrically disposed with respect to the associated supporting members of the electrodes and press framework.

What should one look for in any given pressure and clamping device? How much pressure per square inch of glue area should be exerted? Certainly, crushing pressures should not be applied. Magnified sections of glued joints which have been subjected to crushing pressures show cell walls destroyed with resultant serious loss of shear strength in the wood fibers themselves.[2] Although such a joint will look good from the standpoint of wood failure upon breakage adjacent to the glue line, yet the crushed and weakened fibers may later contribute to delamination because of stresses brought about by subsequent moisture content changes.

It is obvious that the more perfectly the stock is machined, the less is the pressure required to bring the glued faces into intimate contact. Intimate contact is essential when r.f. is used because, wherever there is a void, the moisture is exploded out of the glue, leaving a frothy, crystaline residue which lacks even jell strength.

In the early stages, it was thought that the press should be constructed massively and rigidly in order to force the package to conform to the press which, of course, resulted in crushing pressures wherever any high spots existed. Since wood is a variable substance and difficult to hold to precise tolerance, it soon became evident that the pressure means should conform to the inequalities to a degree, at least, within the crushing strength of the wood. Hence, a flexible pressure means was resorted to.

One method for accomplishing flexibility in the press, resides in providing a multiplicity of pressure sources such as a number of small cylinders instead of one single equivalent source. An alternate device consists in backing up the stock or pressure blocks with some resilient material such as rubber or a mechanical means such as springs. In some instances fire hose would provide an excellent source of resilient pressure and is also low in cost compared to cylinders.

Lack of space in certain operations becomes a factor and to provide sufficient pressure, one must resort to hydraulic means. An hydraulic system may result in slower action as compared to air, however.

Edge-Gluing

Where a hold-down means is required for an edge-gluing device, it is essential that the hold-down "breathe" or release the pressure momentarily to insure that the edge pressure be entirely effective. R.f. power should not come on before pressures have been established. Also, because considerable vapor pressure may be built up during the heating cycle, it is good practice to cut the r.f. power before releasing the pressures. In some instances, quite a time interval should elapse to obviate "blows".

Attempts have been made to design a press and electrode system which might accommodate a very wide variety of glued up assemblies irrespective of length, width and thickness. Such design should be considered with caution because of mechanical complications and radio frequency tuning variables. Usually one is restricted to a variation in two dimensions, especially in the desing of continuous process mechanisms. For instance, a continuous lumber or veneer edge-gluer is restricted to a maximum length of stock measured parallel to the grain. On the other hand, an intermittent lumber edge-gluer is not restricted to length but is restricted to width of panel measured perpendicular to the grain. Assuming equal conditions, naturally a continuous process press will produce at a greater rate than an intermittent press.

The direction in which the stock flows relative to the grain has an important bearing in the production of edge-glued stock. Contrast the job of edge-gluing veneers flowing through the pressure means parallel with the grain to that of panels flowing through the press at right angles to the grain.

Under any circumstances the production rate of an r.f. gluing equipment is contingent upon certain conditions such as the moisture content of the stock, the density of the wood, the type o

[1] Presented at the meeting of the Forest Products Research Society, Pacific Northwest Section, May 17, 18, 1954, at Aberdeen, Washington.

[2] Horne, Roy C., "Surface Characteristics of Coniferous Wood as a Factor in the Strength of Glue Joints." Thesis submitted for a degree of Master of Forestry, University of Washington, 1948.

glue used, the electrode system incorporated in the press, the auxiliary equipment such as the glue spreader, etc., and the power output of the generator. I mention but a few of the variables. The type of electrode system or process used may be, and usually is, a major factor affecting the rate of production.

Electrode System Major Factor

Certain requirements of the product, however, do not always allow a choice of process. In the case of heavy, curved, laminated, structural beams, and structural members in general, exterior moisture-proof glues are required necessitating completely set glue lines before the release of pressure. Under such conditions relatively low production rates may be expected. Practice has established an expectancy of three to four hundred board feet per kilowatt of r.f. output per shift. In the case of a panel press arranged to produce a partial set Z pattern in the glue lines, one may expect approximately six hundred board feet per kilowatt of r.f. power output per shift. The same press equipped with split pole electrodes may put out one thousand board feet per kilowatt per shift. (Note that the above described estimates are based upon intermittent operation).

In a continuous press, a split pole electrode may result in production rates as high as fifteen hundred board feet per k.w. per shift. For instance, one such installation averages twenty-six thousand board feet per shift powered with an r.f. generator rated at fifteen kilowatts of r.f. output.

Scarfed joints, for joining shorts, offer considerable mechanical and r.f. difficulties. They are best handled in a stationary state while the glue is being set. Since scarfed glue joints are very susceptible to arcing, direct contact electrode plates or stray field systems are not satisfactory.

An electrode arrangement known as a self-heating composite electrode has proven to be almost trouble-free, and is especially efficient for scarfing plywood panels. In setting scarfed joints it is paramount that the tips of the scarfs be especially set. Direct contact electrodes leave the tips unset unless a long time cycle is brought about by reducing the power. The composite electrode stores heat which insures setting the tips, utilizing full power to set the glue in a shorter time cycle.

Finger joints, forced end to end, provide pressure at the glue line as a result of the wedging action and consequently may be run through a continuous pressure means. One operation using redwood in gluing 1 x 8 in. shorts utilizes a special split-pole electrode system resulting in a production rate of one thousand board feet per shift per kilowatt of r.f. This is a continuous press flowing the stock lineraly. It is powered with ten kilowatts and is producing ten thousand board feet per shift.

The r.f. method will usually set glue lines faster than an operator can feed stock. This is especially true when the operator must handle a multitude of small pieces.

Stray field electrode systems designed to strike through veneer panels have not proved to be consistently reliable. An example of such an application relates to cored doors. The old glue lines in the panels may divert the electric field from the fresh glue lines and may arc over, with resultant spoilage. Also, the shadows inherent in stray fields leave unset areas which may, at a later date, cause delamination in the finished product due to stresses and subsequent changes in moisture conditions.

In general, an r.f. electric field pattern is not completely uniform both parallel to the glue lines and at right angles to them. This, taken together with so-called fringing effects must be given consideration in the design of electrodes in relation to any given fabrication.

Vacuum Tube

The most essential part of any r.f. application is the radio frequency generator, and the heart of the generator itself is the vacuum tube which converts the slow frequency input power to high frequency output power. Broadly speaking, the vacuum tube and its associated parts which compose the generator, is a device which one might well designate as a frequency converter, for instance, conversion from sixty cycles per second to millions of cycles per second. The resultant high frequency electromagnetic field of force, when properly applied to a load, disturbs the atomic and molecular structure of the substance, and this internal disturbance produces heat within the mass with a resultant internal rise in temperature.

The expression "when properly applied" means that the generator load and connecting links must be "tuned" much in the same manner as organ pipes and musical strings are tuned one to the other. The terms "frequency", "wave length" and "harmonics", etc., are applicable to both r.f. and musical instruments.

What characteristics of an r.f. generator should be observed in the light of suitability for industrial purposes?

Stability is a prime factor. A radio frequency oscillator built specifically for communciations purposes, and when coupled in the conventional manner to a fixed antenna system, may be very stable but, such a generator, when connected to a wood and glue load, may be very unstable for the reason that wood and glue vary rapidly in their electrical properties as the temperature rises and the moisture content changes during the heating cycle.

Generators may be classified as "double-enders" and "single-enders". In the double-ender, the framework of the press is neutral to the pair of charged electrodes, while in the single-ender the press frame itself is used as a so-called "grounded electrode" in opposition to the so-called "live" or "hot" electrode. Experience indicates the double-ender provides the best balance for the alternate positive and negative charges set up across the load and also produces a more uniform placement of heat throughout the material.

Coping with TV and Communications Interference

Industrial r.f. installations are capable of radiation, which if of sufficient intensity, is apt to interfere with communications and television. The advent of television has aggravated the problem, especially in television fringe areas. Even though the level of radiation satisfies the rulings of the Federal Communications Commission, yet enough radiation may disturb television for close neighbors thus involving a problem of public relations. Theoretically, if the load absorbed 100% of the output r.f. energy, then none would be left to radiate into space. Such an ideal condition may only be approached.

Symmetrical disposal of the r.f. circuit elements of the generator and the load with respect to the alternate positive and negative pulses of charge is an important factor in design to reduce radiation because equal and opposite charges arriving in space practically at the same instant cancel each other out. In general, buried power lines help to reduce radiation. The above factors, together with shielding have proven to be very effective and practical, so little apprehension need be had on this score. There are some cases where the type of load is very difficult and impractical to shield and a screened work space becomes necessary.

Efficiency and Investment

What efficiency may be expected from an r.f. generator? Theoretically, the maximum efficiency based upon the input power, is 50 percent. Practically 45 percent may be expected as a maximum. Such a rating appears to be low but is largely offset by the internal heat effect of the r.f. field of force. Compared to conventional heat applications from external sources, the efficiency is actually very high.

What about capital investment, taking the generator alone? At the present

time, in the range of five to twenty kilowatts of r.f. output, the cost per kilowatt approximates $650.

Is there a limit to the power which might be applied to any given load? Too much concentration of power will result in explosive effects and destructive arcing. Bear in mind that an infinitely short time cycle for setting glue would require infinite power. Hence for a given condition, it becomes rapidly uneconomical to shorten a time cycle by the addition of power. Generators which produce excessively high r.f. voltages are not suitable for industrial purposes such as we are discussing. The tolerance of wood and glue with respect to voltage is limited. Increasing the voltage gradient beyond a certain tolerance will result in destructive arcs.

What major factors govern the behavior of a load of wood and glue and the cooking cycle?

To mention a few, moisture content, species, density, ambient temperatures, distribution of moisture content and the type of glue involved, govern the cooking cycle.

Four Basic Glues

Of the four basic glues, namely ureas, phenols, melamines, and resorcins, ureas require the least r.f power for a given time cycle. Phenols probably require the most. Catalysts and extenders temper the behavior of the glue. The process of parallel bonding may be enhanced by adding a small amount of common table salt to the glue, under 2 percent by weight.

Any arrangement of electrodes which results in the process of parallel bonding is by far the fastest method for setting glues. For optimum results, the glue lines should be moist and highly conductive as compared to the adjacent wood. The time cycle, under equal conditions, between parallel bonding and perpendicular bonding may be to the order of 10:1 in favor of parallel bonding.

Glue "squeeze out" always poses a problem, the accumulation of glue on electrodes, conveyors, loading tables, etc., being very difficult to remove. Ideally, glue should bond the individual pieces of wood together with a maximum of strength but should not adhere to the press members, glue spreader parts, conveyors, etc. From a chemical viewpoint, substances which involve molecular charges of opposite polarity readily adhere one to the other. Those having the same charges adhere with difficulty. Butyl rubber versus synthetic glue is cited as an example of the latter type. It has been demonstrated that carbon black used in the vulcanization of rubber has a great affinity for synthetic glues. Hence, by leaving out the carbon black from the surface coating of conveyor belts, it is possible to greatly reduce glue adhesion to these parts. Possibly a glue spreader might be more readily cleaned if coated and lined with butyl rubber.

It is well to note that only certain synthetic glues may be used with r.f. Animal glue certainly cannot be used. Consult the glue manufacturer for glues, catalysts, and extenders best fitted to use with r.f. Glue companies carry on constant experimentation along these lines.

In closing it is logical to predict the development of many more and different applications of r.f. to the wood industry. There is an ever-increasing need for better wood utilization. In turn, this need will, undoubtedly, be met by advances in the techniques of generating high frequency radio waves and in their control and application.

The application of r.f. to wood and glues is by now pretty well established. Both intermittent and continuous presses have been highly developed to conform to the peculiar properties of the r.f. field of force and the variabilities of wood. Untried application of r.f. should be approached with caution mainly because of the economics involved. Many such are in the laboratory stage. Preparation of the wood and the control of moisture content therein are important factors to consider in relation to the use of r.f. Uniform distribution of moisture is of more importance than the quantity involved. Excessive crushing pressures should be avoided. It is practical to reduce radiation to a level which does not interfere with communication and television. Excessive concentration of power applied to a load will result in destructive effects. In most cases the r.f. maintenance may be and is handled satisfactorily by the plant electrician. R.f. is now an important factor in the conservation of wood products and will undoubtedly become more so as conservation becomes more pressing.

Lumber Outlook for 1955

(Continued from page 13-A)

LEO V. BODINE

Executive V. P., National Lumber Manufacturers Association, Washington, D. C.

ings and thereby acquire equity in the buildings. The new housing law will give a boost to home repairs, alterations and additions, another important lumber market. Recent Census Bureau figures indicate that home owners, alone, are spending about $7.2 billion a year to fix up their properties. It is estimated that rental properties, not covered by the survey, add $5 billion. This total is about equal to expenditures for new housing construction in 1954.

The new housing law provides FHA insurance to encourage the rehabilitation of old dwellings and gives the government authority to make loans and grants for certain conservation, rehabilitation and slum clearance projects. In addition FHA expects the long-term upward trend in Title I loans to continue and estimates that about two million individual loans were insured in 1954.

Another feature of the new housing law is that veterans will be able to use unused portions of their $7,500 VA home loan guarantees for home repair and improvement loans. The do-it-yourself movement will continue to figure prominently in the home repair and improvement picture.

Lumber production for 1954 is expected to be about five per cent below the 1953 level. For 1953, the preliminary production estimate is 39 billion board feet, which probably will be revised downward to conform more closely with recent Census Bureau reports. Lumber consumption, which includes exports and imports as well as changes in distributors' stocks, is figured at approximately 39 billion board feet for 1954. This compares with an estimated 40 billion in 1953.

Chiefly responsible for the decline in lumber output during 1954 were the extended strikes in the Douglas fir region. If similar shutdowns do not occur in 1955, if current construction prospects hold up, and if lumber manufacturers take aggressive action to improve their market position, then production and consumption next year should at least equal—and may very well exceed —this year's figures.

Gluing of Furniture Parts[1]

CHARLES M. CAREY

Production Planning Manager, Drexel Furniture Co., Drexel, N. C.

Various types of gluing operations in large furniture plant are described. Conditions that affect gluing operations are discussed. Need for training plant personnel in correct gluing methods is stressed.

DURING THE PRESENT period of re-adjustment economics, it is important for furniture manufacturers to re-appraise their manufacturing techniques in an effort to improve plant efficiency, and to produce better products. Sharing experiences and information, as we do in FPRS is a great help in accomplishing these goals.

Glue Training

The management at Drexel believes in giving its men the equipment, materials and training to do an efficient job. These are also essential for an efficient organization. The quality of equipment and material depends upon the ability and willingness of a company to make expenditures. Training of employees is the least expensive of these necessary factors of production, since immediate and tangible results can be obtained as training progresses.

Gluing is probably one of the easiest subjects to organize for training in your own plant. We recently held a most successful glue clinic for our superintendents, foremen and employees involved in mixing and applying glue.

We recommend the following class room program, when training in proper gluing techniques is needed.

1. Select a man to serve as panel moderator.
2. Select several of the outstanding field representatives of the leading glue manufacturers to serve on your panel. Preferably one to represent each type of glue you use.
3. Have samples of the various glues used.
4. Have samples of good joints, poor joints, correct and incorrect machining.
5. Distribute gluing literature to the men. There are excellent manuals available from glue manufacturers free of charge.
6. Have a plan. Our program lasted for three hours. There were two glue company representatives present who gave 15 minute lectures on the type of glue they sold. An outline of our program follows:

1. Machining—Company Engineer ---------- 20 min.
   a. Type of joints desired for gluing
   b. Carbide-tipped saws
2. Urea-Resins—Glue Representative ---------- 15 min.
3. Animal glue—Glue Representative ---------- 15 min.
4. Conditioning and Moisture Content—Plant Manager ---------- 20 min.
5. Cutting Costs—Purchasing Agent ---------- 15 min.
   10 minute break
6. Quality Control—Laboratory Technician ------ 20 min.

The remaining time was used as a question and answer period.

Class-room training of this type will not solve all gluing problems, but it does give the men a better understanding of the qualities, characteristics and capabilities of the glues they use. Training must continue on-the-job by supervisory personnel who should correct errors in gluing and instruct the employees in proper gluing procedures.

Moisture Content

We obtain the best and most consistent gluing results with lumber dried to a mostiure content in the range of 6 to 9 percent. For RF edge gluing we prefer lumber at 6 percent. A higher moisture content will result in wood of higher conductivity and deprive the glue-line of power. A moisture content of 7 percent for both veneers and cores seems to be ideal for hot-pressing. The apparent discrepancy between the core stock at 6 percent and the desired 7 percent moisture content for hot-pressing is overcome by a humidity controlled conditioning room where the moisture content of the cores is increased to about 7 percent. Higher moisture contents encourage steam blisters and excess penetration of glue into the wood, whereas, low moisture contents may lead to loss of water from the glue to the wood.

Slightly higher moisture contents are used when gluing with room-temperature setting mixes. Best results are obtained with cores at 8 percent and veneer about 9 percent. These higher moisture contents permit better flow of the glue. Here we do not have heat, as in hot-pressing, to aid glue flow.

Machining

With the advent of mass production techniques, the old tongue and groove joints gave way to a smooth, jointed edge. Today, carbide-tipped saws have eliminated the glue jointer in many plants. Our rip saws are equipped with 14 in. 11 gauge saws with 30 carbide teeth. These saws turn at standard motor speeds of 3450 or 3500 revolutions per minute with a chain feed speed of 124 ft. per minute. A sharp, well-balanced saw of this type will produce excellent joints for core stock. Heavy stock for laminating or blocking are surfaced in either a molder or finish planer.

Gluing should be done as soon after machining as possible. There are several obvious reasons for this. Fluctuations in relative humidity will cause varying degrees of swelling and shrinking between boards and often within the same board due to differences in density and grain direction. Also swelling and shrinking can cause out-of-square joints, due to the difference between tangential and radial swelling and shrinking. This can best be illustrated with the accompanying sketch, figure 1.

In cross section, wood shrinks and swells more along the annual rings (tangentially) than it does across the annual rings (radially). Also, the longer the annual ring the greater the shrinking and swelling. Consequently, lumber cut as shown above will lose its squareness upon shrinking or swelling and result in poor-fitting joints.

Joints produced with knives will have some wood compression due to the beating action of the knives, the amount of compression depending upon the knife sharpness and the wood density—the duller the knife and the harder the wood, the greater the compression. Since density will vary between boards and even within the same board, so will the degree of compression. This compressed wood tends to expand and, being compressed unevenly, it expands unevenly, resulting in an uneven edge. It is wise, therefore, to glue before this compression release occurs.

Both saws and knives tear some wood fibers during the cutting process. This tearing is, of course, less with sharp tools. These torn fibers cause little gluing trouble if gluing is done immediately, however, an increase in moisture content during storage causes

[1] Presented at meeting of the Forest Products Research Society, Carolinas-Chesapeake section, June 11, 1954, at Washington, D. C.

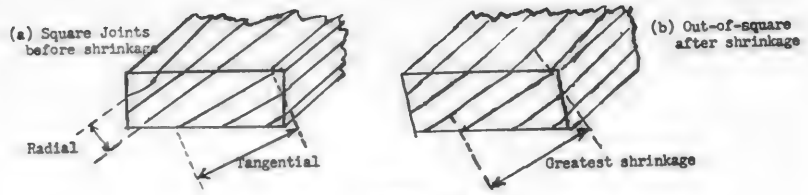


Figure 1.

them to expand, loosen, and rise. These protruding, loose fibers present weak gluing surfaces and thicker glue lines which also produce poor bonds.

Types of Glue

We are now using high solids urea-formaldehyde resin glue and a very high grade of animal glue. The animal glue is used for case and chair assembly, inlaying, drawer assembly and glue blocking. The high-solids urea resin is used on all other gluing operations. Three years ago we maintained two supplies of ureas—low solids for the manufacture of plywood and high solids for laminating edge gluing and post blocking. An all-out effort was made to locate one all-purpose glue for tank storage. After many tests we adopted the high-solids urea resin. The cost per mixed lb. was a fraction higher than low solids ureas but the fact that it could be used for all urea-gluing operations compensated for the slightly higher cost.

So today we use one urea resin, 65% solids urea-formaldehyde with four different formulations as follows:

	Lbs. Glue	Lbs. Wheat Flour	Lbs. Water	Walnut Shell Flour	Catalyst	Table Salt
Veneering (Hot Press)	100	100	80–100	0	7	0
Veneering (Cold Press)	100	50	35– 40	10	7	0
Laminating (Cold Press) Maple, Gum, Beech	100	0	0	12	7	0
R-F Gluing (Edge Gluing and Sub Assembly)	100	0	8.3	0	19.5	1.4

Gluing Pressures

It is difficult to make definite statements as to the pressure required for various types of gluing. We often depend too much on pressure to compensate for bad-fitting joints resulting from incorrect machining. This is especially true on edge-gluing machines. Actually, pressure is necessary only to place the wood in intimate contact during gluing and to create flow and penetration of the glue.

If joints and glue spread were perfect, the above could probably be accomplished with 15 or 20 pounds of pressure per square inch. However, since nothing ever attains perfection, we recognize that additional pressures are necessary to compress the wood slightly and compensate for unequal thickness of veneers and uneven joints in lumber. Pressures are controlled by the softest wood in an assembly. We use the normally accepted pressures of 100 psi for soft pine, 150 psi for poplar, mahogany and gum, 200 psi for oak, maple and beech. Pressures much in excess of these will either crush the wood or cause undesirable compression resulting in showing through of cross-band joints or core defects on the face veneers.

Edge Gluing (Radio-Frequency)

Drexel has several types of Radio-Frequency edge gluing machines, but because of limited space only one will be discussed in this paper. This machine is of the batch-type with a capacity of 50 in. x 86 in. Side and top pressure is obtained with hydraulic cylinders. An air-operated pusher automatically feeds the stock from the lay-up table into the press. An average curing cycle for a full press load of 4/4 poplar core stock is 25 seconds. Strip-type electrodes, top and bottom, produce stray-field curing. A 15 KW R–F generator supplies the power. The generator is tuned to the press load depending upon the wood thickness and species of wood. Excess power will cause arcing, burning and resulting bad joints. We have found that 2000 R–F Peak Volts per inch gives the most satisfactory results. This machine is used to glue all panel stock used in the plant including 5/8 oak and sycamore for drawer side stock. We have successfully glued stock up to 4 in. in thickness.

Glue is cooled in buckets to 40°F before mixing in a box type refrigeration unit and mixed just prior to use. A typical mix is as follows:

18 lbs. 65% solids urea-formaldehyde resin
3½ lbs. of special R–F hardener
4 oz. of Na Cl (Table Salt)
1½ lbs. cold water

The table salt increases the conductivity of the glue mix and tends to direct more power from the wood to the glue line.

There is an important exception to the above procedure when gluing mahogany and white pine. Apparently minerals in these woods make it highly conductive and subject to arcing and burning. Mahogany and white pine can be glued successfully by eliminating the table salt from the glue mix and reducing the R–F Peak Volts per inch to 1000. This, of course, means a longer curing cycle but will result in excellent bonds.

Cores are removed from the press, placed on factory trucks and separated with stickers one half inch thick and approximately one inch wide. These trucks are then rolled into a conditioning room.

Conditioning of Cores

All lumber cores are conditioned prior to finish planing to minimize the danger of sunken joints and warping. Both ureas and hide glue increase the moisture content of the wood adjacent to the glue line approximately 2 percent. This is true no matter what gluing method is used. The moisture content must become uniform throughout the core *before* planing. The recommended conditioning cycles are:

Time	Temperature	Relative Humidity
7 days Room Temp.	(80°F)	30%
4 days	120°F	35%
2 days	160°F	45%
16 hours	200°F	55%

We have been very successful at Drexel by using a combination of the above cycles, overnight at 160°F and four days at room temp.

For best results, cores should be veneered immediately after finish planing. The reasons are the same as those mentioned under the heading "Machining."

Sub-Assembly (Radio-Frequency)

One of our plants has been equipped with R–F presses for all sub-assembly work. This is accomplished with five R–F presses which were designed and constructed in our engineering department. These presses are air-operated and powered with 2 and 5 KW generators. The glue formulation is the same as on the edge-gluing machine. These presses are used primarily for blocking posts; banding tops; bed assembly; case end assembly; and applying moldings.

A variety of brushes, round ratan sticks and small glue spreaders are used to apply the glue.

The power generators are installed and adjusted to the presses by a representative of the manufacturer. Tube replacements and minor adjustments are made thereafter by our own electricians.

Electrodes may be of either brass or aluminum. We have had very good success with 1/8 in. aluminum, 1 1/8 in. in width with riveted joints. Pressure forms are made of shellacked hard maple faced with heat-resistant 1/8 in. rubber.

When gluing mahogany the same precautions are taken as with edge gluing of this species. The salt is eliminated from the glue and the voltage reduced. Excess squeeze-out of glue increases the danger of arcing so it is advisable to wipe off excess glue before applying power.

When bad bonds occur in R–F gluing they can usually be attributed to poor machining; excessively high temperatures; or the premature application of R–F power. We are all acquainted with the results of bad joints, but the results of high temperature and premature heat are not often seen in other types of gluing. Extremely high R–F heat often produces what appears to be a crystallized glue. The glue is brittle and lacks strength. One function of pressure is the elimination of air bubbles in the glue. If heat is applied before this process occurs, the air bubbles will expand and become entrapped in the hardened glue. This results in a frothy-appearing glue which also lacks strength. We have installed time delay switches on the presses so that the R–F power is applied after the joint pressure develops. Control of the heat is accomplished by tuning and adjustments of the generator to maintain the desired power at the glue line and consequently the correct heat.

There are advantages and disadvantages of Radio-Frequency gluing, the most important of which are as follows:

Advantages:

1. Rapid cure; increases production if properly used and applied.
2. Stock may be handled and machined soon after removal from the press.
3. Eliminates many screw presses and clamps.
4. Lower labor costs.

Disadvantages:

1. High initial investment.
2. Requires highly skilled operators.
3. Service men not immediately available in the event of generator failure.

We feel that the advantages far outweigh the disadvantages, where high production is required.

Gluing Plastic Laminates

Plastic laminates are usually produced of several sheets of phenol-impregnated kraft paper faced with a melamine impregnated surface of decorative paper or veneer.

The most satisfactory core for these laminates seems to be Douglas fir faced with 1/16 in. mahogany or soft pine. Lumber core panels tend to show a transfer of core joints and glue lines through the laminate. Pressing should be done at room temperature (Cold Pressing) because prolonged heating may cause crazing of the laminate as well as warping of the panel. Several types of glue can be used—ureas, contact cements, or poly-vinyl resin emulsions. We have been very successful with a rich mix of urea-formaldehyde resin (65 percent solids). Pressures must be low, not over 50 psi., to eliminate the danger of transfering panel defects through the laminate. With experience, this low pressure can be accomplished with retaining clamp pressure only.

Bonding with a plastic laminate can be done with any of the glues mentioned above. Contact cements seem to be the most practical since their use requires no special presses or forms. Sufficient pressure can be obtained with a hard-rubber hand roller. There are several good contact cements available. All require a delayed open-assembly time of 10 or 15 minutes which can be reduced by force-drying with ovens or infra-red lamps.

Quality Control

It has been well-stated that an item of furniture is no better than its weakest glue joint. Certainly, strong glue, glue joints are essential in all quality lines of furniture.

Any glue quality control system must include control of the raw materials, mixing, application in production and inspection of the final product. We are fortunate in having a well-equipped and well-staffed testing laboratory organized for the purpose of testing resin glues.

Samples of the tank car or truck of resin are picked up by a laboratory technician as it is received at the plant. This glue sample is tested immediately for Ph, viscosity and solids content. The Ph must not be less than 7.0; a 65 percent solids resin must be within the range of 63.0–67.0 percent solids. Wet and dry strength tests are then conducted on plywood shear specimens.

Significant variations are brought to the attention of the glue manufacturer for action. So far the variations have not been of a serious nature and have resulted only in an occasional cost reduction on a glue shipment.

The plant superintendent and glue-room foreman are informed of the test results.

Resin glues are received in tank-car or tank-truck lots, stored in underground tanks and piped to the glue-room. The man mixing the glue merely opens a lever-type electric valve which actuates a pump at the tank. Glue is pumped directly into a calibrated measuring vat above the mixer. The same vat is used for measuring water for the mix. Accurate scales are used for measuring wheat flour, walnut shell flour and catalysts. We insist that weighing buckets and scales be kept clean at all times. Gram scales are available in each glue room so the foreman can check the glue spread. This is done several times a day to maintain a glue spread of 40–50 lbs. for cold pressing and 30–40 lbs, for hot pressing, per thousand square feet of single glue line. (Porous wood requires more than denser species. Pressure gauges are inspected for accuracy every six months by a company engineer. Each press is equipped with a correct pressure chart. Hot presses are checked daily for steam trap operation. Hot press platens are checked several times each day for the correct temperature.

The glue-room foremen still rely to a great extent on the old knife test to determine glue bond quality. This method does not reveal information about water resistance but an experienced man can learn much from this test. We have found no other way to get an indication of glue bond quality so quickly. We feel that there is a place for the knife test. In addition to this method, the foreman selects several lumber core panels at random from each day's production. These panels are tested at the laboratory on a plywood shear testing machine for wet and dry strength.

Development of a Sawmill Layout[1]

D. K. SAUNDERS
Saunders Bros., Westbrook, Maine

Allowing time for ideas to develop, striving for minimum manual handling, seeking advice of men on the job, are among recommendations that can lead to savings in handling and increased production.

THIS PAPER PROPOSES to illustrate the development of a layout for a sawmill specifically designed to produce boards for making rod dowels and furniture pins. While this layout might not be used for many other end products, the principles involved should be applied as well to other operations. In a general way, the problem of developing a layout is the problem of developing one efficiently operating machine out of an assembly of machines and operations.

Since an effective layout is closely dependent on final production requirements, a brief description of dowel operations should help explain our governing conditions. We aim to get a maximum number of standard length dowels, either 36 in. or 48 in. long, in diameters ranging from 1/8 in. through 1 in., with the emphasis on 1/2 in. and smaller. They are turned, or more properly, moulded, in multiple on planers with matched top and bottom heads, from boards about 4 in. wide. The operation with which we are concerned here involves converting bolts into boards, which are then dried, green from the saw.

The price of any one dowel, furniture pin, or the board from which they come, is so low that we are forced to consider seriously every unit of time we can spend on a single piece. At the same time, competition from other materials has always forced us to the same end. For this reason, a large part of our efforts have been devoted to finding ways of handling materials in bulk with little or no waste effort, or better yet, of finding ways by which we can avoid handling at all. To illustrate the latter point, our boards are stuck on factory trucks, where they stay through drying and later storage, being fed into the dowel machines directly from these trucks.

Two sawmills produce boards, each mill consisting of a bolter saw for removing slabs and boxing out poor quality heart wood, a trimmer for squaring the ends of resulting blocks, or plank, to a uniform length, and a twin band saw from which we get two boards at a pass. Two general types of bolts supply the mill, either white and yellow birch, or beech and maple, in lengths from 39 in. to 51 in., and within these groups we may sort in the yard to take care of quality requirements for certain dowel diameters or end uses.

[1] Presented at meeting of the Forest Products Research Society, Northeast Section, April 29, 1954, at Williamsport, Pa.

History

A program of rebuilding and layout improvement in the turning and other final operation departments led to our being forced to expand and replace our old dry house and storage sheds. Like the man who starts with a new linoleum and finishes with a complete new kitchen, we eventually realized that our sawmill buildings must be replaced, even though improvements over the years in handling methods and sawmill arrangement had left us well satisfied with production and sawmill quality.

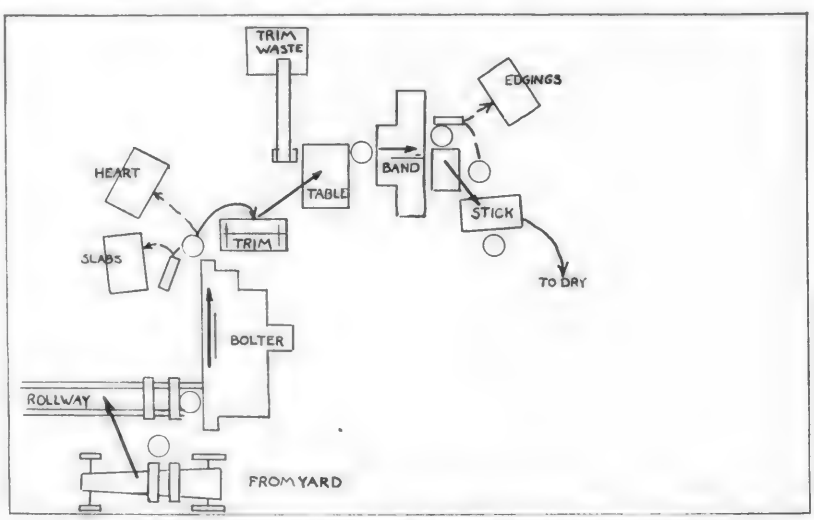
We had moved the sawmill from the center of the bolt yard to adjoin a sticking room and the dryhouse. A rubber tired industrial tractor with trailer hauling close to a cord had replaced a horse-drawn jigger, or dray, with one-quarter cord capacity, and we had changed our sticking methods so that factory trucks carried the stock undisturbed from the sawmill to the dowel machine. We depended on manpower to load bolts and transfer them to skids from which the bolter sawyer could roll them directly on the same level to the saw carriage. The offbearer trimmed the planks to length and piled them on a table for the band sawyer; he also tied slabs into bundles and piled them on a factory truck with the redheart waste. A fork lift carried the slabs to a reserve fuel pile and the redheart squares to a pulp wood pile. The band sawyer fed the plank from the table, which was convenient for his operation, and the offbearer sorted the boards and waste edgings coming from the saw. A tender bundled edgings and passed boards to the stickers.

Operating efficiency and layout seemed satisfactory, but the condition of the structure made new buildings necessary. At the same time we were starting a new operation with a diesel driven bolter and trim saw built into a box trailer, designed to supply us with plank by trailer truck working from locations on good roads near large birch lots, or from concentration yards convenient to supply areas. Fitting the flow of plank into our existing layout was clumsy, and we felt that starting fresh would give us a chance to work efficiently from either the trailer mill or the local bolter saws. We also felt that we could mechanize several purely manual operations.

Philosophy

The following requirements guided the process of layout development:

1. Mechanization—We wanted to eliminate manual handling at every point possible, unless such other factors as judgement in sorting might be involved.



Original layout.

2. Versatility—The mill must be arranged to take a load directly from a supplier's trusk, from our own yard vehicles, and to receive a maximum trailer load of plank at a point where it could flow smoothly to the band saw. At the other end, boards on the sticks must flow easily into the dry kilns or equally well to a point from which they could be carried to an air drying yard.

3. Comfort—The mill must be a pleasant place to work, and contribute psychologically to good production. We had grown to realize that with no stimulation on management's part, the two crews in the existing mills had developed a friendly competition, and the same thing was true between the bolter and band saw elements of each crew. We felt our part lay in planning so that this rivalry should not be disturbed. This decision promptly threw out early suggestions that we put the two bolters together in one location and the band saws in another, or that we put each mill or half crew into a separate room.

4. Waste Disposal—Defining as waste all material which could not be converted into dowels, we wanted to approach the ideal of dropping it at the point it developed, giving it no further thought. Under the existing arrangement, sawdust was blown to a fuel storage bin, solid trim and edgings were pushed in hand carts to the boilers, slabs were divided between the reserve fuel supply and reinforcements for shavings bales, and the redheart squares joined unacceptable bolts for resale as pulpwood, and at some point each of these was being handled manually.

Beyond these basic requirements, previous experiences in laying out dowel operations led us to believe that careful thought spent on layout might possibly yield us production and quality improvements even over the obvious and expected results.

Development

With the decision to build began a long period of tentative planning. This included questioning nearly all details of every process and piece of equipment, sounding out members of the crew for suggestions and preferences, and making many scribbled sketches. This process continued even to the point where the mill was set up and operating. Observations and measurements showed the amount of floor space required for machines and operators, and operator's comments on possible improvements were invited even to the extent of giving serious thought to what would at first glance appear ridiculous.

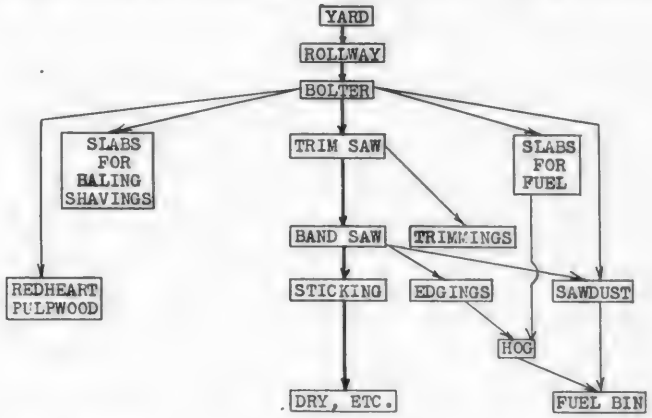
At this point we made small scaled wooden patterns of the floor plan of each machine, periodically setting them up on a table into layouts for quick visualization. Meanwhile we put similar paper patterns in layout on paper tacked to a 10 foot bulletin board, located so conspicuously that it intruded on our thoughts even while we were on more routine jobs. This had the advantage of giving us a chance to spend free time going over possible weaknesses in arrangements which at first looked promising.

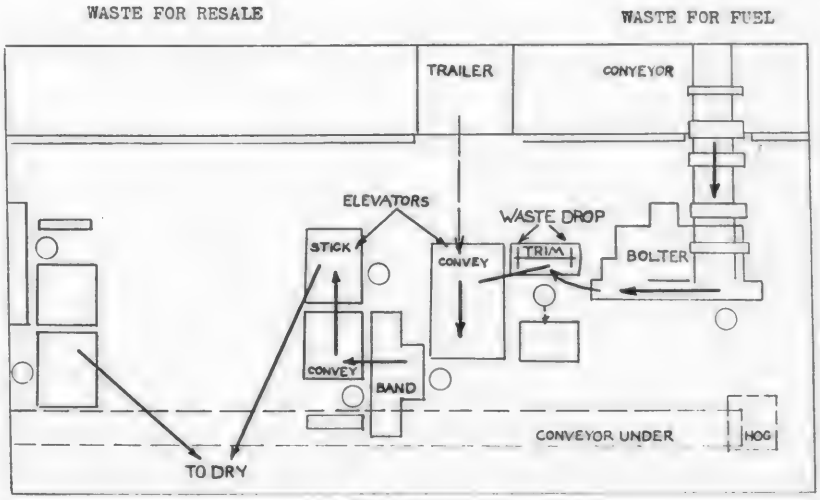
Review

When a layout went on the bulletin it could be expected to look like the perfect answer to every problem, but usually a few days' observation would raise questions over details which proved to need more thought. Even when everything seemed satisfactory, someone would suggest a radical change, and often a complete reversal of machine position or material flow brought a definite improvement. This phase of planning lasted several months, continuing even after the basic dimensions of the building were crystallized. In fact, certain details were not fixed until after the general layout was fixed and work well along. For example, we decided that elaborate conveyor systems from the yard were less versatile than hauling in by the existing method, and had already started using a chain conveyor which inched bolts directly into position at the sawyer's hand. For a short time we unloaded by hand from a ramp at the side of the chain, but decided to try a fork lift tractor unloading directly to the end of the chain. This entailed adding a sort of hopper, and now it is possible for the bolt man to pick his load from the storage pile and drop it on the chain without leaving the tractor seat.

The accompanying sketches show the contrast between the original and final layouts. While the material still flows through as many steps, nearly every transfer is on a conveyor designed for a specific purpose, eliminating hand lifting from machines to piles on tables set for feeding later operations. Where stock might accumulate between machines there now are hydraulic elevators to keep the top of the pile at a convenient height, so that an operator reaches in a natural motion for each new piece of stock.

The first plans called for a mezzanine to keep services, blowers, and waste handling off the main floor, but it seemed wise to take advantage of gravity. For this reason, solid waste trimmings, edgings from the band saws, and slabs that are not saved for shav-





Revised layout.

ings bale slats, all drop through the floor at the point where they develop, landing on conveyors in the basement. This waste goes to a hog and there is joined by sawdust also drawn through the floor, the mixture being blown to a fuel storage bin adjoining the boiler house. This method eliminates the problem of moving several truckloads of solid waste a day, as well as the work of tying edgings and slabs into bundles.

Two problems were met by directing the flow from each mill to the center of the room rather than directly toward the dry kiln. Sticking the finished boards in the center of the room allows a tender to move easily from one crew to the other as he may be needed, and the trailers from the outlying mill are backed to the sawmill wall so that loads of plank can flow directly on the same level to the hydraulic lift tending the band saw. The final method of handling trailer loads of plank illustrates the value of repeatedly reviewing plans to arrive at a simple answer. Several ideas for handling this stock presented themselves, including gantry cranes, live, and free rolling conveyors built into the trailer floor. We finally decided to load the plank on skids formed from a few of these same planks, moving them off the trailer with a hand operated skid truck, which normally transfers them directly to the hydraulic lift feeding the band saw. The building has enough free space, however, so that several of these trailer loads could be stored if necessary without interfering with operations.

The fact that the floor between the actual sawing operations and the dry kilns is roomy, with large doors at each end, not only allows us to hold trailer loads, but gives room to store a good part of a day's sawing ready to enter the dry house, or to pick up boards on the sticks with fork lift yard trucks for air drying.

Results

A glance at the original and final layouts will show that in spite of a review of every process and piece of equipment, no radical change in operations was introduced. The flow of good material remains essentially the same, although manual handling has been somewhat reduced; the principal difference lies in the fact that waste moves automatically. It was this general similarity in layout which led us to feel that any gains would come from less manhours devoted to waste, but it turned out that even these small improvements in arrangements led to noticeably increased production.

In summary, experience in developing layout both for sawmills and for final operations leads to the following recommendations:

1. Take plenty of time to allow ideas to develop.
2. Analyze the operation, first as a whole, then in detail, to insure a minimum of manual handling, and to allow a reasonably steady flow with no bottlenecks.
3. Seek comments and advice on details from the men actually on the job.
4. Use any possible aids to visualize the problem; sketches, scribbled notes, detailed plans, process flow charts, patterns, and models to scale.
5. Periodically review all plans, and follow through any alternatives to a logical conclusion before eliminating them.
6. Make a point of reversing your plans to get a fresh view of the problem, both in general layout and detail.
7. Don't feel that you will reach perfection, and expect even after the new layout is set up and operating to spend considerable effort correcting oversights and smoothing out details.
8. Finally, bear in mind that a clear, simple layout seems to develop only after the more complex ones have been exhausted.

A Briton's Appraisal of the Timber Industry In the United States[1]

T. S. MALLINSON
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Are we at times "too close to the forests to see the trees?" There may be an idea or two for each of us in the following refreshing views of a visitor from abroad.

THIS IMPRESSION must begin with an explanation defining its limitations. My experience concerns a tour that I have made since mid-January of this year, during which I have visited a number of companies whose interests range from veneer cutting, sawmilling, plywood manufacture, tree farming, and reforestation, to sales of the products of the industry. I have been north to the land of the maple, birch, and basswood; east to the coast and the ports handling timbers from Africa; south to the aromatic cedar lands, and further south where grow the red oak, white oak, poplar and cottonwood. In the deep south there were timbers from South and Central America, as well as cypress and other idigenous species. And when in my travels I reached the west coast there were the great timbers of the northwest, the Douglas-fir, spruce, Ponderosa pine, redwoods, and those imported from the Philippines.

The limitation of my material is therefore its diversity, and my impressions broad and general, and because of my limited experience, almost entirely non-technical. The subject is the Trade and F.P. Industry as a whole. For convenience the two will be considered together as "the timber industry". The principal distinctions between all that I have seen of our own trade and industry, and that which I have had the privilege of seeing in your country can be considered under six headings. 1. A comparison of the species in common use and their source. 2. The methods of manufacture. 3. The methods of marketing. 4. The Trade organizations. 5. Reforestation programs. 6. A few conclusions.

The annual consumption of all timber products per capita in the United States is around *6½ times as great as the average for Western Europe. Further, the U. S. consumes almost 2/3 of the entire world supply of temperate hardwoods. Despite this tremendous demand upon the timber resources of the forests in this country it was only in 1940 that the United States began to import more lumber than it exported, while the United Kingdom, with a consumption per capita less by far, is dependent upon the importation of 85.7% of the combined* hardwood and softwood timber requirements. The circumstances may be changing, but current relative import and export values will emphasize the major distinction between the industries and trade of the two countries:

[1] Presented at the meeting of the Forest Products Research Society, Midwest Section, September --, 1954, at Madison, Wisconsin.

IMPORTS AND EXPORTS OF FOREST PRODUCTS LUMBER AND LOGS AND WOOD MANUFACTURES

	U. S. A. (1953)	United Kingdom (1953)
Imports	$350,205,776	$499,260,835
Exports	$105,082,429	$ 9,515,940

The source of supply has a very marked effect upon the form of the industry, as well as upon the cost of material. My journey has shown to me the extent of material self sufficiency of the plants of various kinds in each area. A great part of the industry stands amid its main source of supply. This is not true of our industry in the United Kingdom, for the big users of timber tend to site their operations within easy reach of the coastal ports, normally with direct access to waterways serving these ports. The greater interest of the timber industry in the U. K. is, in fact, trade and not manufacture.

There is another factor which has an effect of emphasizing the problems of material supply in Britain. The common home grown timbers of the United Kingdom have by no means the utility of the wide variety of timbers common to the United States. The volume of our home grown timber trade is in species which can be numbered on your fingers. Oak, ash, elm, beech, sweet chestnut, horse chestnut, sycamore (acer pseudoplatanus), larch, scots pine, and spruce. There are others but the quantities are small.

We have no equal of the white and yellow birch, no quantity of hard maple for our floors, no volume of basswood or poplar for core materials, or gum or Douglas-fir for the production of inexpensive plywood. We are sadly short of walnut for veneer, and unable to supply more than a small portion of our needs for softwood for the 300,000 houses per year we must build to make up for war damage and a growing population. All this therefore results in our material costs being comparatively high, because of the distances involved in the importation of foreign timbers, and the value set upon the standing tree in the U. K. due to scarcity.

My impression develops out of this, that there is a very much wider use of home grown timber in the U. S. than there can ever be in the U. K. Equally there is a smaller need for imported timber, and, in consequence, a smaller variety of foreign woods reaches U. S. markets. This results, it would seem, in the manufacturers of consumer products, particularly furniture, being reluctant to try new species, partly for reasons of economy, and partly because of a belief that the consumer will not go for any but the traditional decorative uses of woods.

Common to our market of hardwood lumber are timbers such as Abura, African Walnut, Afzelia, Agba, Avodire, Dahoma, Danta, Doussie, Gaboon, Gedu, Nohor, Guarea, Idigbo, Iroko, Makore, Mansonia, Obeche, Opepe, Ramin, Sapele, Utile and many others, over 100 at one London wharf alone. Our own business in veneer supplies the needs and fancies of architects in England, and our stocks include over 170 different species from all parts of the world.

Many of the species now common to our market have not established themselves entirely in place of those for which they were brought in as substitutes. Economic conditions may change the source of our supply and the species in common use. The relative part that hardwoods from the U. S., and from Nigeria and the Gold Coast played in our total imports of hardwoods before the war and recently is shown here.

PERCENTAGE OF TOTAL U. K. HARDWOOD IMPORTS

	1938	1953
U. S. A.	34 percent	1 percent
Nigeria and Gold Coast	4.4 percent	40 percent

Perhaps of the species mentioned only Ramin and Abura have established a market in the furniture industry, for example, and a resumption of trade in American hardwoods in the event of the alleviation of restrictions on dollar purchases by the U. K. would probably have a direct affect upon the variety of imports from West Africa as well as the volume.

It is my impression that we are still in Britain more conscious of the materials we use, not only because of the part they play in conversion costs, but also because of the natural warmth and beauty we seek and find in wood. No one visiting the U. S. could fail to be impressed with the production methods and efficiency which pervades nearly all phases of your manufacture. The quality of the product is, and should be as impressive as the method of manufacture, because the development of a market for mass produced materials and products which are relatively inexpensive has been due to the spur of competition, which in itself has required that quality be maintained and ever improved.

Driving Force Is Competition

The methods of manufacture in the U. S. have changed and developed very rapidly in recent years. That is immediately obvious to a visitor to any branch of industry. So much equipment is new even in the older plants, and so much of the organization is clearly in progress of improvement. The driving force is always competition; the obstacle is the final cost of conversion. That applies in both countries, and the effects that it has upon methods of manufacture in the two countries can be distinguished almost solely because of the different relationship of the factors of this cost—materials, labor and overhead. It is only a question of emphasis, and although the efficiency of handling methods in the U. S. is the most outstanding feature the visitor sees, emphasizing the attention paid to labor costs of conversion, there is nonetheless a growing consciousness here of the cost of materials. While in England we may be more inclined to examine material yield at all stages of manufacture as the major factor in our conversion costs, plants in this country are not unconcerned with the same problem. It has therefore seemed strange to me that the problem has been considered here so differently and perhaps even so much from one angle alone. The material yield is expressed in terms of useable veneer, for example, in the plywood or furniture industry. The concern is to obtain a given standard yield. But it is still possible that the fault causing waste may not be in the veneer alone but in the thinking of the plywood or furniture manufacturer.

Regimentation or Individuality?

I have in mind hardwood face veneers, where material costs are necessarily of great importance. What the clipper now condemns to the hog for fuel would make veneer of real beauty and character if the manufacturer were to accept the true nature of wood and allow it at least its minor imperfections. There seems to be a belief that it is necessary to obtain thousands of feet of perfect face veneer, the same in color, and texture, and grain throughout for quantity production of panels or furniture, even though this opens the door for direct competition from printed, painted, and other synthetic materials.

I have seen the care that is taken by the buyer of veneer in the furniture industry to purchase veneer free from every pin knot or character mark, and then I have watched the extreme efficiency with which first a primer, then a filler, then a sealer, then a toner, and finally the finish is applied to render walnut indistinguishable from mahogany, and mahogany indistinguishable from a plastic coated print. Surely this isn't right. *The appeal of wood is its natural warmth and character. It can be no less unreasonable of the veneer manufacturer to cut veneer always to achieve uniformity, with a condemnation of anything unusual to the category of drawer bottoms, than it is for the panel or furniture manufacturer to take the veneer and obliterate its warmth and character. It is all in the hands of the manufacturer, for the consumer has shown his regard for the natural effect by the present popularity of knotty pine, and character* paneling, while the

magazines for example promote materials in their natural form, "the textured look", and even the competitive industries of plastics, and wallpaper advertise products which are "just like wood". The cry rings sadly of the dangers of dwindling supplies of walnut, oak or mahogany, and at the same time, angrily because the walnut, oak and mahogany which is available is not sufficiently like walnut, oak, or mahogany to be acceptable. Would not the yield of veneer in these and other species be very considerably increased simply by allowing the beauty of the wood to creep back into the finished article?

Imports Greatly Increased

Competition is clearly the cause of another interesting change in the industry about which many are concerned. Since 1939 the value of imports of forest products to your country has increased from $260,268,000 to $1,260,706,000 in 1952. Imports of hardwood plywoods have taken this pattern of increase in very recent times.

COMPARISON OF IMPORTS OF HARDWOOD PLYWOOD WITH U. S. DOMESTIC PRODUCTION

1951	9.5 percent
1952	12 percent
1953	24.7 percent
1954 Trend	30 percent

It is happening universally and products of other regions are being seen more and more on markets in the U. S. At the same time new materials are also being developed with new properties and appeal. Their cost, resistance to heat or wear, convenient application, and uniformity of color are meeting the demand. Yet an interesting effect is the immense effort being made by wood users to develop products which stand on their own merits, better than any of the substitutes. Wood products in the U. S. are not becoming less varied or less in volume in face of competition from other regions and materials. Every concern among plywood manufacturers I have had the pleasure of visiting is engaged in the development of a number of new products soon to be launched upon the market, or in the production of some line unknown a few years ago, many of them making use of materials which were at first thought to be in direct competition with wood, and a threat to the industry.

Perhaps the most striking aspect of the timber industry in the U. S. is the method of marketing its many products. Increasingly it has become necessary for the industry to bring its products to the attention of the ultimate consumer, who is to enjoy their use. Competition has driven the individual manufacturer into new fields of advertising and promotion. Competition from other materials has brought the industry together to form associations to promote wood products collectively.

"Do It Yourself!"

The industry has suddenly distinguished the ultimate consumer as "the man in the street", or, as he whom we sometimes call in England, "the man on the Clapham Omnibus". And so it has started to sell not only to the retail distributor or the trades and professions responsible for industrial and constructional use of the material, but also to this far wider market for potential customers. We have not wakened to this in England, for no-one has yet let loose the cry, "Do it yourself", and catered to the ensuing rush.

It is this slogan and the movement of material which it has brought about that is especially impressive about the marketing methods in your industry. But it has been made possible by the adoption of a wholesale-retail system not only in the furniture industry but for plywood also, and to a lesser degree for lumber. The manufacturer of plywood deals with the wholesaler and the wholesale organizations in turn with the retail outlets. Their customers are big accounts in industry and contractors, plus a multitude of individual customers requiring just enough to be able to do a little job themselves. So the manufacturer now makes a product which this individual can use readily, and the wholesaler, not only "sells" the retail distributor on the idea, but also the consumer by means of advertising and promotional material. This is surely a remarkable development in the industry, especially for the plywood manufacturer, for more and more his product ceases to be the raw material for some further manufacture or construction and becomes a finished article for a specific use.

The wholesale retail set up does not exist so fully in the timber trade in England. It is still exceedingly difficult for the Clapham bus rider to purchase a walnut panel 4 x 8 foot good one side. He would not know where to go and chances are he would meet with almost impossible problems whether he went to a hardware store, a builder's merchant, a building contractor, a softwood or hardwood merchant and perhaps even to any but the smallest of panel manufacturers. Our outlets for timber products still take the pattern that they took before the war. Advertising is institutional, though some of the advertising of the Timber Development Association speaks for the industry on the general merits of wood, even, oddly enough, in posters in the double decker Clapham omnibus. But there has been little attempt to bring about a "do it yourself" movement, because the retail outlet for the products is by no means so well developed in England.

Training of Salesmen

However, the advance of the industry into this field in this country does bring about a problem of salesmanship. I have been struck with the caliber of salesmen here in every line of business. I have also noticed a very different emphasis in their selection and training from that which is common in England. A salesman here is chosen for his selling ability expressed by his personality or previous experience in any field of selling. In England these factors are considered, however more attention is paid to his technical training in the manufacture and nature of the materials he is to handle. This is due in part to the greater emphasis upon materials from all aspects, and partly to the form of distribution which brings the manufacturer or the importer in close contact with the building contractor or shipbuilder, for example, using the material, in the absence of a formal wholesale-retail outlet. I have the impression that concerns in the U. S., *manufacturers, wholesalers, and retailers, are becoming increasingly aware that it is no longer wise to have the salesman say, "here is our product, the rest is up to you", though this is being shown more so far. I believe, in the form of advertising and promotional campaigns than by a movement towards the technical training, of salesmen.*

Just as competition within the industry has brought about a highly developed sales system and elaborate advertising and promotional programs, competition from other materials has brought the trade organizations in this country more closely together. Integration of interests has been an easier task in England because of the smaller scale of the industry and territory involved. We have, in effect, only two national organizations and membership of the Timber Trades Federation entails support of the Timber Development Association. The T.T.F. covers all aspects of importing and merchanting including brokerage, hardwood, softwood, plywood, pitwood, and other interests of the industry. The T.D.A. is concerned with all that its name implies, including the dissemination of information, and the promotion of wood products. Almost 100 percent of importers, merchants, brokers, etc. are members of the Federation and so contributors by a levy based on turnover to the T.D.A. The two organizations cover the composite whole of our trade and industry.

In the U. S. I have had the pleasure of visiting several of the many associations which represent every aspect of

your industry. Their work is always interesting and their achievements individually are often a great argument for such specialized representation, but I have heard the thought expressed so often that the forces working separately for the promotion of forest products should combine resources, and campaign together to make their effort concerted and more effective.

The program of reforestation in the U. K. has developed very considerably since the decision of the Forestry Commission in 1919 to set the target for replanting and afforestation at a total of 1,770,000 acres.

Here we have the picture of the events which affect our supply of home grown timbers today:

In addition to the state schemes, work is being done by private organizations and farmers. Of the 67,610 acres brought under forest in 1953, 13,000 acres were planted by private estates with state aid, and 5,200 acres planted without the aid of these grants. Several timber companies in the U. K. have added reforestation to their own interests and maintain nurseries and personnel to plant small areas of hardwoods and softwoods outside the bigger program of afforestation undertaken by the Forestry Commission.

The U. S. with 1/12 of the population of the world uses nearly 1/2 of all the timber utilized throughout the world, and yet the Forest scene is becoming nevertheless more encouraging:

There may be some way to go yet, but all out efforts instigated by certain associations, perhaps notably the Walnut Association, have a most impressive record of achievement in reforestation in this country. I have been interested in the programs of tree farming, perpetual or sustained yield, selective felling, two cycle felling, ring barking and other methods of good forestry, as well as schemes for collection of seeds and replanting such as the great drive for walnuts.

The forests of the U. K. by strict interpretation of the felling quotas can supply but 394,800,000 board feet of our total needs in softwood, hardwood, and plywood amounting currently to 3,427,081,920 board feet, just 11.5 percent. It would seem very important to the industry in the U. S. to continue the development of reforestation programs to insure that it can retain its independence and develop in its present form without falling back upon the support of an ever greater proportion of raw material from distant forest regions. This must be so in face of present competitive conditions and I have found that this is well understood wherever I have been.

And so I have realized five outstanding impressions of the trade and industry in the U. S.:

1. The adaptability of the industry. The appreciation of changing circumstances and the willingness to take a calculated risk.

2. The appreciation by the industry of the part that modern scientific development can play not just in creating new materials which compete with wood, but in opening altogether new fields of utilization of forest products.

3. The growing understanding of material costs and the search for new means of utilizing waste, such as chipcore, wood flour, etc.

4. The great field of the "do it yourself" market and the change that this has brought about in the consumer relationship.

5. Finally the willingness of all concerned in the timber industry to share information and better the general knowledge of techniques for the advancement of the industry as a whole. I feel that this is perhaps the finest tribute to the industry, that it should be so keen to show to everyone how it has kept pace with the modern world. For this I am personally sincerely grateful, for there can be no experience more valuable for people interested in the use of forest resources anywhere in the world than a study of the great timber industry of the U. S.

COMMERCIAL FOREST AREAS U. S. A. SAW TIMBER REMOVAL AND ANNUAL GROWTH COMPARED

(BOARD FEET)

	Hardwoods	Softwoods
1. Saw Timber Removal—1944		
Commodity Withdrawal	14,067,000,000	35,591,000,000
Destructive Drain	1,296,000,000	2,939,000,000
	15,363,000,000	38,530,000,000
2. Annual Growth—1945		
Saw Timber	13,453,000,000	21,848,000,000

3. Ratio of Removal to Growth—All Timbers
1920 ..... 4.34 : 1
1944 ..... 1.02 :: 1

FACTS ABOUT FORESTRY IN THE UNITED KINGDOM

	Forest Acreage	Percentage of Total Land Area	Acres Per 100 of Population
U. K.	3,315,200	4.3%	10
U. S. A.	630,158,000	32.5%	479

2. Forest Area 1939–1945—
Acreage Replanted or Afforested: 110,476
Acreage Cut Over or Devastated: 1,310,000 (38% of Forest Area)

3. Forest Policy 1945
A) 5,000,000 Acres of Forest area by 1995
B) Felling Quotas:
e.g. 1953

Hardwoods	312,000,000 F.B.M.	Plus further quotas for smaller poles, pulpwood, etc.
Softwoods	82,800,000 F.B.M.	

Source of Data

1. Lumber Industry Facts—1953. National Lumber Manufacturers Association.
2. T.D.A. Year Book of Timber Statistics—1953. Timber Development Association, 21 College Hill, London, E. C. 4.

The Furniture Industry in British Columbia[1]

K. G. FENSOM

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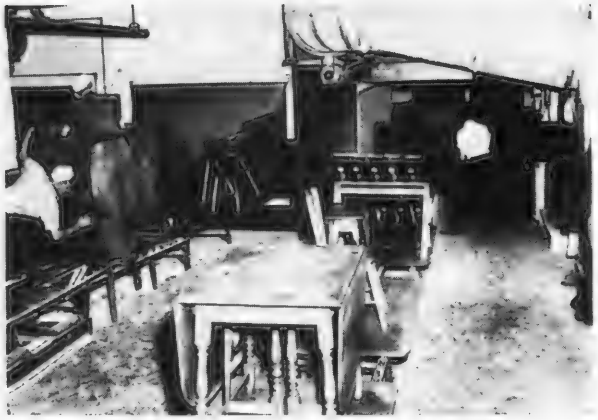
THE PRODUCTION of furniture is as old and honoured craft and the styles characteristic of different eras and epochs have reflected the tastes, living habits and imaginative concepts of those periods. Much present furniture design, however, is still being influenced by the old master craftsmen, as was Early American, Colonial and Duncan Phyfe in the United States and French Provincial in Canada.

Through this long period of furniture evolution—and in spite of the fact that hundreds of different species of wood have been used at one time or another—the dominant decorative woods have been variously oak, walnut, mahogany, maple and birch. Maple and birch are the comparative newcomers to the "big five". Each of these woods possesses strength, durability and beauty. Each works well under tools, takes a good finish, stays in place well, and is available in quantity in many parts of the world.

[1] Contribution from the Vancouver Laboratory of the Forest Products Laboratories Division, Forestry Branch, Department of Northern Affairs and National Resources, Canada. Paper presented at a meeting of the Pacific Northwest Section, Forest Products Research Society, Portland, Oregon, February 1st and 2nd, 1954.



Assembly lines used to advantage.

Finish and appearance are important.

British Columbian Woods

Few of these woods occur in British Columbia where the forest is predominantly softwood, but maple, alder, and birch are valuable secondary hardwods (see Table), all of which are utilized in the manufacture of furniture.

Of these woods, however, only maple and alder are used—and these to a very limited extent—for exterior decorative surfaces.

The red alder of British Columbia, *Alnus rubra* Bong., is the only important commercial species of alder in Canada. The tree ranges from 8 inches to 30 inches in diameter, and from 30 to 100 feet in height. The wood is pale yellow to reddish-brown in colour, has a pleasing but not accentuated figure, takes a smooth finish, works well under tools, and is of medium hardness and weight.

The broadleaf maple, *Acer macrophyllum* Pursh, is one of ten species of maple native to Canada, where it occurs only in British Columbia. Trees grow to a maximum diameter of 34 inches and to a maximum height of 90 feet. The wood is white to light brown in colour. Its properties are very similar to those of alder—it takes an excellent finish, glues and nails well, is easily worked, and has a fine, uniform texture. It is heavier than alder, but not as heavy nor as strong as sugar maple.

A not inconsiderable quantity of Douglas fir plywood, 3-ply, 5-ply, and 7-ply, 1/4 inch to 3/4 inch in thickness, is utilized in furniture manufacture, and is all produced locally. It is used chiefly as core stock.

Hardboard, used extensively for drawer bottoms and mirror backs in 1/8 inch thicknesses, is also produced in the province.

Furniture manufacture in British Columbia provides an outlet for the utilization of native woods in an area where the volume of lumber export is considerably in excess of local consumption. There is greater diversification of industry generally today than at any time in the past, but not to the extent that there can be said to be a completely balanced provincial economy. Therefore, any type of manufacture which contributes to diversification and which uses a raw material grown and harvested in the province has a stabilizing effect, and this is true of the furniture as of other secondary industries.

SPECIES CUT IN BRITISH COLUMBIA, 1952[2]
(ft. b.m.)

Douglas fir	2,022,043,970
Cedar	677,283,925
Spruce	655,893,267
Lodgepole pine	119,880,698
Hemlock	948,276,008
Balsam	278,899,154
White pine	46,986,859
Yellow pine	46,310,093
Cypress	8,916,343
Larch	115,383,602
Hardwoods (exclusive of cottonwood)	7,979,924
Cottonwood	10,111,600
TOTAL	4,937,965,443

[2]"Report of the Forest Service, 1952", Department of Lands and Forests, Province of British Columbia.

Imported Woods

The established decorative furniture woods, such as walnut, oak, mahogany, ash and others in minor quantities, are imported. Of these latter, light finished oak is the popular favourite at the present time.

All decorative face veneers are imported, mostly from the United States. These are chiefly oak, ash, walnut, and mahogany, 1/28-inch in thickness, though minor quantities of veneers of exotic species are also imported.

Furniture Production

Canada: Although furniture is manufactured in each of the ten provinces of Canada, the principal production centres are in southwestern Ontario and eastern Quebec. In 1951, the Dominion Bureau of Statistics reported 1,430 establishments in Canada, 1,017 of which were operating in Quebec and Ontario. The net value of this production was placed at $83,043,068, or about 84 per cent of the total national net of $98,474,043, of which 43 per cent was case goods (wooden furniture), 19 per cent upholstered furniture, and the remainder metal furniture, springs, mattresses, pillows, cushions and comforters

British Columbia: It was further reported that the net value of similarly classified furniture manufactured in British Columbia was $7,415,149, or slightly more than 7 per cent of the total in Canada.

These comparisons indicate that furniture manufacture is not a major industry in British Columbia where the annual combined gross value of lumber and pulp and paper manufacture exceeds $500,000,000. Nevertheless, British Columbia is the third largest furniture manufacturing province in Canada, and its 189[3] furniture manufacturing establishments are an essential part of both the national and provincial economy.

In British Columbia, the manufacture of case goods (wooden furniture) and upholstered furniture are about equally important from the standpoint of total dollar value. Lumber, veneer, bolts, plywood, blocks and squares comprise about 30 per cent of the total cost of materials. Probably not more than 25 per cent of all the case goods purchased retail are manufactured locally. Of the remainder, 70 per cent is imported from Quebec and Ontario, and 5 per cent from the United States and other countries. There are no statistics with reference to imports from eastern Canada, but in 1952 all furniture imported from the United States and other countries into British Columbia was valued at $264,510—practically all case goods on which the duty was 25 per cent. On a comparable dollar basis, the value of case goods manufactured in British Columbia is estimated roughly at between 2 and 2½ million dollars—upholstered furniture at about the same figure—and that of imports from eastern Canada at about 3 and 3½ million dollars. The manufacture of metal fur-

[3] The Furniture Industry, 1951—Dominion Bureau of Statistics, Ottawa, Canada.

niture, springs, mattresses and other products not made of wood is a smaller percentage of the total than in the rest of Canada.

Approximately 80 per cent of the upholstered furniture sold in British Columbia is manufactured in the province. This type of manufacture is divided 80/20 between those who upholster and assemble only, and those who make the whole piece from the frame through to the final assembly.

Many manufacturers make only a single part or group of parts, such as chair seats, drawer sides, centre guides, framing, front rails, and so on; but few are organized on an assembly-line basis.

Export

In spite of heavy importation, 142 pool cars of furniture were shipped from Vancouver—the centre of the industry in the province—from January through October, 1953. These cars averaged 16,000 lbs, in weight and consisted of 75 per cent case goods and 25 per cent upholstered furniture. These shipments went to the prairie provinces of Alberta, Saskatchewan and Manitoba. It is both surprising and creditable that British Columbian manufacturers have been able to compete so far east as Manitoba in a market which is much more accessible to large production centres in Ontario.

Manufacturing Trends

The furniture industry in British Columbia is in a more fluid state than that in eastern Canada. Many of the smaller establishments are one- and two-man carpenter shops making furniture to the customer's sketched designs. They do not specialize in the manufacture of any particular type of furniture, but take what comes to their doors. Hence there is very little continuity in type trends in respect to this kind of manufacture.

The few larger manufacturers provide greater stability to the industry than do the smaller ones, but there is bound to be uncertainty regarding continuity of specific items. The factors contributing to this uncertainty are: the high cost of labour in British Columbia; the limited supply of suitable native hardwoods; the necessity of importing decorative woods and veneers from the southern United States and other distant regions; and the fact that very few of the many required materials other than wood are of local production. Manufacturing costs are therefore high as compared with those in most other furniture centers, and production schedules must be frequently altered to meet outside competition. When these adjustments involve too great a capital expenditure, a plant is forced to close or sell, and, while such ownership changes are not too numerous, they occur frequently enough to affect adversely the stability of the industry.

The two main types of manufacture are case goods and upholstered furniture. At the present time, bedroom suites constitute by far the major portion of case goods manufacture. Only small quantities of dining room suites, kitchen furniture, nursery furniture and dinettes are produced, though at different times in the past there has been emphasis on these various items. Occasional furniture, all wood or partly wood and partly upholstered, is manufactured in minor quantities, as are certain specialty items and unpainted furniture.

The cost of furniture items manufactured in British Columbia is not infrequently double that of similar items produced in eastern Canada. Many of these latter items can therefore absorb the high cost of a 3,000 mile freight haul ($5.18 per 100 lb. from Toronto and Montreal to Vancouver), taxes and retail mark-up, and still undersell a similar item produced in British Columbia. To meet this competition, development has been along the lines of reduction of multiple machine operations to a minimum, resulting in a comparatively low write-off against capital equipment.

Types of Furniture

Upholstered: There is a much greater production of upholstered furniture in British Columbia in relation to the entire output than in eastern Canada. Most of the framing is economically made in stock patterns, but some of it is custom-built to specification. Methods of framing, however, do not vary greatly, and differences in price of product are largely determined by the quality of the covering fabric, the price of which ranges from $1.50 to $30.00 per yard. Both kiln-dried and air-dried lumber is used for frames. Most furniture lumber, however, is kiln-dried down to 7 or 8 per cent moisture content.

Case Goods: Case goods manufacture is characterized by a number of different make-ups. There is the solid wood type, usually native birch or alder with a maple or walnut finish. Some solid wood furniture is made of native maple and spruce but more is constructed of imported oak and ash. Whitewood furniture is mostly made of spruce, but a specialty line of knocked-down unfinished parts readied for easy assembly is made of Douglas fir plywood. Some case goods parts are solid cores—usually native alder—with overlays of imported decorative veneers.

Case goods assembly.

Edge banding with electric strip heaters.

Hand sand clean up on case goods.

Lumber Grades and Utilization

There is some flexibility in the grading of hardwood. It is graded according to the rules of the National Hardwood Lumber Manufacturers Association, Chicago, Illinois, but the grading is off the good face instead of the poor face as specified. Grades vary slightly depending on the source. The principal furniture grades in 5/4 stock are No. 2 Common and better and No. 3 Common for alder, and No. 1 Common and better and No. 2 and 3 Common mixed for maple, birch and cottonwood. Some lumber is purchased mill-run, and there is a difference of opinion as to the relative economy of mill-run versus graded lumber.

It is possible that more clear-cuttings can be obtained from a complete mill-run of lumber than from selected grades only, but the waste percentage is much higher for mill-run, and this loss might cancel out a possible gain in clear-cuttings. No utilization studies have yet been conducted to determine the absolute relative economies in these two types of lumber purchase, nor have accurate measurements been made of the actual waste which develops in furniture manufacture. It varies greatly at different plants, but in general it appears to fall in the range 12 to 25 per cent for plywood, 25 to 35 per cent for lumber, and 30 to 40 per cent for veneer. These are formidable amounts of non-utilized wood volumes, and the possibilities for the future are more in the direction of reducing waste residues by standardized manufacturing techniques than by discovery of new uses for this particular kind of waste.

Factors Governing Waste

The amount of waste is governed not only by the quality of the lumber, plywood, veneer and dimension stock going into the plant, but also by the kind of drying, machine efficiency, machining procedures, effectiveness of gluing techniques and other factors. When there are variations in standard lumber thicknesses, the percentage waste is greater.

Either poor air-seasoning or poor kiln-drying will result in degrade of lumber, and this in turn will adversely affect the waste factor, as will also such items as maladjustment of machine speeds, cutter heads, cutting angles and rate of speed, and other practices which lower the quality of the finished product. British Columbia is no different from other furniture centers in that some plants are more efficient than others, but individual manufacturers are hampered in their efforts to keep informed as to the latest techniques, developments and related research because of lack of organization on a province-wide basis. Whether because of this or other reasons, there are some quite marked differences in manufacturing techniques within the general over-all conforming pattern.

Manufacturing Techniques

Gluing: The rapid gluing of wood with synthetic resin adhesives by means of radio dielectric heating is done at one plant. The advantages of dielectric heating have been proved in industrial application in connection with the edge-gluing of core stock and veneers, assembly gluing with thermo-setting adhesives, the gluing of veneers in plywood panels, and the bonding of curved plywood. No research in this field has been undertaken at the Vancouver laboratory, but fundamental studies and studies of other possible practical applications are being made at the Ottawa laboratory.

Edge-bonding of veneers is done with and without electric strip heaters; and at one plant glue is applied directly behind the ripsaw.

Machining: At another plant, all lumber from the dry-kiln passes to a double surfacer, then to cut-off saws, thence through the plant as required; at another all material goes through a sticker. At some plants, parts are mortised and tenoned, at others the same work is done on shapers which can be more quickly and easily reset for small volume runs. One plant has drill presses, routers, belt sanders, vertical borers, table saws, a double-end tenoner, single shapers, cut-off saws, rip saws, molding sanders, double-spindle shapers, horizontal borers, 6-spindle mortisers, jointers, bandsaws, a double surfacer, veneer trimmers, a glue spreader, veneer taping machines, and a cold press; but at others all parts are made on a few machines only. One plant equipped with one shaper, a planer, four cut-off saws and three belt sanders is turning out over 500 bedroom suites monthly.

Most leg parts are solid, and a few cross-grained or spiral-grained pieces find their way into production. When legs are large and knobby, they are sometimes built up of glued-together component parts, the whole subsequently being turned to obtain the final desired shape. Joints are mortised and tenoned or dowelled. Screws and glue blocks are used for reinforcing in places where excessive stress in service can be expected. The better drawers are dovetailed front and back. Very few plants have sufficient diversity of production to justify a heavy capital investment in equipment which is not continuously in use; and, as has been stated, simplified manufacturing procedures on a few machines are the rule rather than the exception.

Kiln-drying: Schedules developed at the Vancouver Forest Products Laboratory are mostly being used in kiln-drying lumber in British Columbia, but only two furniture plants have installed dry-kilns. Much of the kiln-dried lumber used by the industry is obtained from sawmillers equipped with dry-kiln facilities.

Finishing: Native softwoods and low grade hardwoods in the lower price brackets, when used for outside parts, are usually painted or treated with some other obscuring type of finish. Most finishes, however, are applied for the purpose of enhancing the natural beauty of wood and making it more attractive. Expert finishing gives special character to a wood surface and the distinction of quality furniture is in large measure achieved through fine finishing.

Sometimes there is too great a time lag after the final sanding before the finish is applied. The wood fibres and vessels at the surface are compressed in the various operations of machining and sanding. The surfaces so treated will stay smooth and polished as long as the moisture content remains unchanged. However, this surface compression is released when the moisture content changes, and this produces a fuzziness and roughness which, though often barely detectable, will adversely affect the resulting finish.

Sometimes, too, the surface pores are not cleaned sufficiently before the finish is applied. Such surplus sander dust may be the cause of pinholes in lacquer or varnish coatings and unevenness in colour distribution.

Standard finishes are used in British Columbia. The species of wood employed present no special problems in their treatment, and it can be said that these treatments are adequate. Very little high priced cabinet making or hand carving is done, but there are a few English craftsmen who do detailed and intricate work, and who are able to apply expensive hand finishing techniques, since the price return for this type of craftsmanship is sufficient to cover the additional cost of preparation.

Design: Much of the design is original and is changed frequently to conform with new trends and demands. Some designs, however, are purchased, and some again are used on a royalty basis.

Conclusion

The governing factors in furniture manufacture are economic in British Columbia, which has few natural advantages as far as this type of production is concerned. Competition with the eastern product is so severe that it can only be met by selectivity in production, sustained good retail outlets and management, and by economical design. Technical problems are being solved, but there is need for some kind of central association to represent the industry and to disseminate ideas.

It can be expected that careful planning and increased consumer demand—i.e., greater population—will stimulate the growth of this important industry.

Around the World in Forest Products Research and Development by G. M. Hunt

Liberian Forest Products Industries—Dark Past, Bright Future

E. W. FOBES

Assistant Forester, U. S. Operations Mission to Liberia[1]

LIBERIAN FORESTS have a vast variety of tree species that produce fascinating woods of many shades and densities ranging from the light weight corkwood to the dense, dark red ironwood. Some of these woods are very susceptible to decay and termite attack while others are very resistant. One tree is called "elephant stick" because of its large size and grey bark. Other local names are equally descriptive. The variety of products that can be made from these woods staggers the imagination, yet today only a small fraction of this potential is being used.

Only meager information is available regarding the origin and history of Liberian forests, but it is probable that the first inhabitants found the country completely covered with trees. Their major concern was food and shelter. Although the forests provided these essential products, the former was neither sufficient in quantity nor regularity so the people turned to agriculture. This required clearing land of forest growth. Then, after a crop or two, the heavy rains reduced the soil fertility so that it became necessary to clear new land and abandon the old. Forest growth quickly returned to abandoned land and in a presently unknown period of time again returned to the original composition and character of the virgin forest.

Centuries of shifting agriculture developed antagonism of the forest that is depicted by forest or "bush" devils and demons. Oddly enough the masks made to represent these and other spirits were probably the first forest products produced. Then as today, all essential needs were derived from the forest and included bows and arrows, mortars for grinding food, furniture, and other products. Liberian development has been truly a "wooden age."

Foresters Fobes and Torkel Holsoe inspect hand-carved wooden masks and figures. While not utility forest products these are important in the social and spiritual life of rural Liberia.

The battle against the forest has continued until recent years, resulting in extensive depletion of a potentially valuable resource. Steps are now being taken to conserve and put this resource to use. There is now one band mill in operation at Bomi Hills and six circular sawmills besides a number of pit sawing operations. The output of these operations is now consumed locally and is insufficient to meet the demand. In addition to local demand, several European countries are interested in importing Liberian forest products. Railroad ties make up the largest volume of wood going into any single product. These are cut on the band mill and, unlike in most American tie mills, the logs are sawed in multiple tie lengths. This practice produces long length side lumber and contributes materially to high output and efficiency. Although most of the lumber is used by the sawmill owners to develop their concessions, some of it finds its way into Monrovia, the capital city.

There are several woodworking plants in Monrovia, and they all remind one of the custom plants found throughout the United States. Production is in accordance with the orders on hand and varies from window and door frames to window sash and furniture. The number of woodworking machines in each plant varies, but a great deal of the work is done by hand. Workmanship in general is good and in some cases the finished product is as good as that of the best equipped shops in the United States. Origin of the machines is an interesting sidelight. In one plant the machines are from France, Germany, U. S. A., and Switzerland.

Family size forest product operations are numerous. Chairs and beds are major products. These are transported to market as head loads. Individual pieces for these items are split out and shaped by hand tools. The workmanship is crude and little attempt is made to finish the product. Another family size operation is the making of baskets. These are made from bamboo and palms. Workmanship on baskets is in direct contrast to that of the above items. These products are very well manufactured in a vast variety of shapes and sizes. Fuel wood and charcoal are locally important forest products, but do not enter extensively into markets. These products are generally produced for personal use, with an unknown quantity being sold in the few large cities. Both products are obtained mainly from farm clearing operations.

Timber felled in clearing for a farm is left to dry until near the end of the dry season. The area is then set on fire and broadcast burned. There is no danger of fire spreading to the surrounding timber. After the fire is out, there remains a considerable quantity of charcoal, charred and dead wood. A portion of this is gathered and used for fuel. Charcoal is sometimes made in pits dug in the ground and in earth-covered heaps.

Although there is a growing demand for paper and paper products, there is none produced in Liberia at the present time. Old newspapers are used exten-

[1] A contributed paper. The U. S. mutual security program of cooperation with nearly 60 countries of the free world is authorized by Congress "to maintain the security and promote the foreign policy of the United States." Technical cooperation—joint programs of teaching and training—with the less developed countries is an important part of this effort. One of the technicians actively engaged in this work is E. W. Fobes, a U. S. forester of many years' experience in Wisconsin and other states, now an employee of the Foreign Operations Administration.

Fobes was, before his service with U. S. Mutual Security Program, a member of the U. S. Forest Products Laboratory, Madison.

Timber types and topographic features are recorded along the Gio Forest Boundary. Fobes is training forestry aide in use of diameter tape for measuring trees. A start is being made in Liberia to establish national forest reserves and inventory forests.

Fobes and two trainee aides measure logs at a small sawmill in the interior.

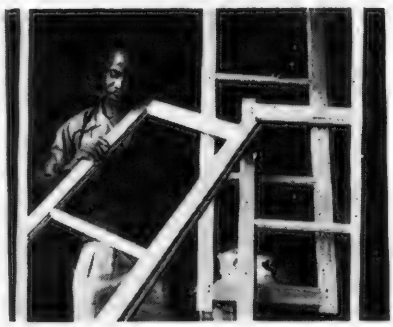
Locally manufactured chairs at a woodworking plant in Monrovia.

sively for wrapping parcels in stores, and all newsprint is imported.

At one time quantities of dyewood were shipped from Liberia, but these have now apparently been replaced by synthetics. One chemical forest product has been in use many years and is still used very effectively. It is the use of bark for tanning leather. Several species of trees in Liberia apparently have a rather high tannin content, and it is possible that this is true of some woods.

A product of the forest that cannot be overlooked is wild game. This is the major source of protein for the rural population. Using a hypothetical figure of 1/10 of a pound of meat per day per person indicates that the daily yield of the forests is over 100,000 pounds.

Liberians have been dependent upon products from the forests since the first inhabitant, but like pioneers of many countries have fought the forests. The turning point has now been reached and an increasing number of people look upon the forest and its products as a benefactor instead of a foe. The rate of future development is dependent upon the amount of foreign technical know-how and capital invested in cooperation with present Liberian effort.



Woodworker inspects window sash made in a local custom woodworking plant.

Note: These are FOA photos by Griff Davis, U.S.A. Operations Mission, Monrovia, Liberia.

Forest Products Research in Finland

Central Association of Finnish Woodworking Industries

IN 1945 the forest industry companies in Finland established a joint body for forest work studies and rationalization known as *Metsäteho*. The character of forest work in the different parts of the country is fairly uniform, and it was possible therefore to concentrate the work in one central body. At present, membership in Metsäteho is held by 110 forest industries and VAPO, the state railway fuel bureau.

The tasks of Metsäteho comprise: 1. Investigations aiming at the following goals: Rationalization of forest work and timber transport; Rationalization of the general organization of forest business; Determination of fair standards for relations to forest work wages; Creation of a basis for measures aiming at the improvement of the social standing of forest workers. 2. Publication of the results of investigations. 3. Following progress made in the branch, both in science and in practise, at home and abroad. 4. Carrying-on of publication, training, and publicity work directed at rationalizing forest work.

The subjects for research are suggested by the member companies and accepted by Metsäteho Committee, according to their current interest or general importance. Hitherto, the investigations have primarily concerned the time studies, research on performance of forest workers, research on mechanized tools, tractors, etc., and rationalization of the transport. Research under way at the moment includes e.g. investigations into timber haulage by wheeled tractors, studies of the floating possibilities of unbarked timber, experiments with transportable barking machines, time studies of work achievements in the preparation of birch pulpwood and of small-diameter pulpwood, chemical barking, and color marking of goods to be floated.

The results have been published in a separate series of "Publications by Metsäteho," in which articles are summarized in English. So far the series includes 30 publications. Advance information on investigation results and topical information on the various questions arising in the branch have been issued by editing a leaflet styled "Metsäteho Report," of which 102 issues have been published so far. A series of textbooks for forest work foremen and forest workers has been inaugurated, and three issues have thus far been printed. Other activities include rationalization courses arranged for foresters employed in the forest industry, and series of lectures and films arranged for forest work leaders and the pupils of ranger schools.

The activities of Metsäteho are superintended by a council consisting of the chief foresters of the largest forest industries in the country. It also includes representatives of the Association of the Finnish Woodworking Industry Employers, and of the forest workers' own associations. The chairmanship of the Committee, from its establishment to 1948, was held by Dr. Eino Saari. Mr. Jarl Lindfors, Forest Councillor, was elected the new chairman.

The director of Metsäteho is Mr. Jaakko Vöry, Licentiate of Forestry. To him are subordinated 8 graduated foresters, a number of time-study workers, computers, and clerks.

[1] A contribution by J. Vöry, Director, Metsäteho, E. Esplanaadikatu, 2, Helsinki, Finland.

Abstracts From Current World Literature

Editor's Note: Since June, 1952, we have been privileged to reproduce, as a special service to FPRS members and readers, abstracts from a variety of sources, below. One of these is the highly valued "Forest Products and Utilization Abstracts," published in England. Recently we were advised that we had been reproducing a rather excessive selection of their abstracts. This was not in the spirit of the original intent which was simply to give our readers a cross-section of the type of service regularly available through such sources. We wish to apologize for exceeding our agreed use, and also to suggest to FPRS members desiring a complete world-wide abstracting service in any field of forest products that they make inquiry through these excellent journals. Complete abstracts are an invaluable adjunct to any research endeavor whether large or small.

Properties of Wood

Higgins, H. G. Factors influencing the plastic deformation of timber and plywood in compression. *Aust. J. appl. Sci.* 4 (1), 1953 (84–97). 14 refs. P.R.

Presents the results of an investigation of the relative effects of different factors on the plastic deformation of wood under compression at right angles to the grain. It has been found that solid specimens are subject to glide' along rings, which given anomalous results. Discusses the advantages of adopting as yield value the pressure, or stress, at which appreciable residual deformation takes place, determined from a series of independent tests at different loads kept constant during a test. The duration of loading appears in such tests to be an important factor in residual deformation only at higher pressures. An investigation on the effect of time on total deformation shows that the deformation/time curves might be amenable to rheological analysis. Glues used in the plywood specimens have considerable effect on plastic deformation. As the moisture content increases (below the fibre-saturation point), the residual deformation increases, and the yield value declines. Residual deformation varies with species, due mainly to differences in density rather than in structure. *From author's summary.* [Forestry Abrtsacts, V. 14, No. 4]

Sweetman, H. L., Benson, D. A., and Kelley, R. W., Jr. Efficacy of aroma of Cedar in control of fabric pests. *J. econ. Ent.* 46 (1), 1953 (29–33). 7 refs.

The aroma of Cedar oil (from the heartwood of *Juniperus virginiana)* in a commercial cedar plaster had no repellent or toxic effects on *Tineola bisselliella, Attagenus piceus* or *Anthrenus vorax.* No definite conclusion could be reached concerning the possible protective value of the aroma of Cedar in well fitting chests. [Forestry Abstracts, V. 14, No. 4]

Prat Roure, L. De. Distintas caracteristicas de los corchos segun su empleo industrial y tratamiento adecuado de los alcornocales con miras a su obtencion. [Different characteristics of cork, according to its uses in industry, and the management of Cork Oak stands, in order to obtain such characteristics.] II Congreso Nacional de Ingenieria, Instituto de Ingenieros Civiles de España, Madrid 1950, Vol. IV, 1951 (247–57). [Span.]

Discusses the history of the cork industry in Spain, grading of cork, differences in quality, size, texture and colour, and treatment of the stands in order to obtain the types required in the market. [Forestry Abstracts, V. 14, No. 4]

Kisser, J., and Steininger, A. Makroskopische und mikroskopische Strukturanderungen bei der Biegebeanspruchung von Holz. [Macroscopic and microscopic structural changes in wood subjected to bending stress.] *Holz Roh- u. Werkstoff* 10 (11), 1952 (415–21). 28 refs. [G.g.] P.R.

Besides the two load values usually determined in bending strength investigations, viz. maximum (rupture) load (I) and load causing gross (macroscopic) compression failures (II) at the compression face of the test specimen, the authors introduce a third load, namely that causing compression failures visible only under a microscope (III). It has been found that the ratios I/II/III are almost identical for Spruce, Silver Fir, and European Larch, when determined for the same moisture content; these ratios, moreover, are independent of m.c. for m.c. below 20–30%, and can be expressed by 1·9/1·52/1. The I/II ratios found by the authors agree well with figures quoted by Staudacher [cf. *For. Astr.* 5 (35)], while the authors' ratios III/I are very close to Staudacher's creep-load/maximum-load ratio. [Cf. *For. Astr.* 13 (No. 636).] [Forestry Abstracts, V. 14, No. 4]

Preservation

Hetrick, L. A. and Moses, P. J. Value of insectides for protection of Pine pulpwood. *J. econ. Ent.* 46 (1), 1953 (160–1).

A number of insecticides were tested on freshly cut and stacked Pine pulpwood in the form of a 0·5% spray. Four weeks after treatment the wood was examined for insect attack, and an evaluation of the insecticides was made. All provided some protection.

The preparation of abstracts from world literature in many languages is so highly specialized and costly that the Forest Products Research Society has no abstracting service of its own. For the abstracts in this issue of the JOURNAL the Society is indebted to the respective abstract journals indicated, from which they have been selected with the kind permission of the editors. Readers wishing information in addition to that given in these abstracts should consult the original articles referred to. Copies or additional information can not be supplied by FPRS or the abstract journal. The journals from which abstracts are published in this issue are as follows:

BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY, published monthly at Appleton, Wisconsin by the Institute of Paper Chemistry, subscription price $25 per year. This Bulletin publishes over 3,600 abstracts per year on subjects of interest to manufacturers of pulp, paper, fiber board and allied products.

CHEMICAL ABSTRACTS, published semimonthly by the American Chemical Society, Executive Office—1155 Sixteenth Street, NW, Washington 6, D. C., subscription price $60 per year plus postage. This abstract journal publishes many thousands of abstracts annually with broad coverage of world literature in the entire field of chemistry and allied subjects.

FOREST PRODUCTS AND UTILIZATION ABSTRACTS are published quarterly by the Commonwealth Agricultural Bureaux of London, England, as a separate reprint of decimal sections 3, 7, and 8 of Forestry Abstracts, for the facility of those interested chiefly in the field of wood utilization. The abstracts are prepared by the Commonwealth Forestry Bureau, Oxford, England, and the utilization section contains about 1,200 titles and abstracts per year from literature in some 30 languages and covers all aspects of forest utilization from cutting and extraction through marketing, mechanical, and chemical processing to minor forest products. FPRS members interested in obtaining the complete issues of Forest Products and Utilization Abstracts should communicate with the Secretary of the Society.

TECHNICAL BULLETIN OF THE FURNITURE DEVELOPMENT COUNCIL is published bimonthly by the Council at 11 Adelphi Terrace, London W. C. 2, England. The Technical Bulletin publishes hundreds of abstracts and reviews from world literature annually, relating to the various phases of the furniture manufacturing industry. Subscription price is $5 per year.

BHC gave excellent results. Chlordane and toxaphene killed some of the attacking insects but failed to prevent infestation. Aldrin, dieldrin, endrin, heptachlor and isodrin were of intermediate value. [Forestry Abstracts, V. 14, No. 4]

Orman, H. R. The holding power of staples in creosoted posts. *For. Prod. Res. Notes N.Z. For. Serv.* 1 (4), 1952 (11–7).

Tests were made on untreated Totara (*Podocarpus totara*) and on creosoted and untreated Larch (*Larix decidua*), Douglas Fir (*Pseudotsuga taxifolia*) and Corsican Pine (*Pinus nigra* var. *calabrica*). The following results were obtained: (1) Larch and Douglas Fir held staples better than Corsican Pine and when not creosoted gave similar results to Totara. (2) Creosoting reduced holding power of shear staples by 25%. (3) An increase in staple size gave a marked increase in holding power in untreated and a less marked increase in creosoted wood. An increase of ½ in. in shear staple size in creosoted woods counterbalanced the loss in staple-holding power caused by creosoting. (4) Barb staples gave lower values for holding efficiency than shear staples in both creosoted and untreated posts. [Forestry Abstracts, V. 14, No. 4]

Wood Finishing

Dickinson, T. A. Ceramic finishes for wood. *Wood Working Digest,* U. S. A., Vol. 56 No. 5, May 1954, pp. 121–2, 124, 126, 2 illus.

A flame finishing technique makes it possible to apply glass-like ceramic coatings to the surfaces of wood products. They are rather expensive and difficult to apply, but they are very resistant to heat and since they are poor conductors they will also protect the wood from heat. Theoretically at least, it is possible to obtain a transparent coating by this method as well as an opaque enamel finish. Most ceramic materials are very hard, but lack resistance to abrasion. For fireproof table tops and other furniture components this can probably be overcome by using waxes and other materials which are known to prolong the life of organic coatings. The technique consists of ejecting a fine refractory powder under air pressure through a hot gas flame. The powder particles are temporarily melted by the flame and, if they are applied in a series of thin layers, they can be fused on untreated wood surfaces without transmitting enough heat to cause damage. Spray guns similar to those normally used for metallizing are suitable for this technique. [F. D. C. Tech. Bul. V. 4, No. 22]

Materials

Schwankl, A. What wood is that? *Franckh'sche Verlagshandlung,* Germany, 1953, 146 pp., 158 illus., 40 specimens, 26s (in German).

Although this book is written in German it will be of some value to those who do not understand the language. There are 40 specimens of colored veneers mounted on cardboard sheets at the back of the book. These are labelled with their German names, but the equivalent English names are given elsewhere in the book. In a 42-page table the same 40 species of timber are classified according to color, hardness, weight and several other physical characteristics. Each of these 40 species is also described individually in the next chapter. These two sections could probably be understood with the help of a dictionary by anyone who has a slight knowledge of German. The glossary of specialized terms may also prove a useful supplement to the scientific dictionaries available. [F. D. C. Tech. Bul. V. 4, No. 22]

Stillinger, J. R. and Currier, R. A. Relative humidity, moisture content, and dimensional stability relationships in hardboard of three manufacturers. *Oregon Forest Products Laboratory,* U. S. A., Report No. T–7, February 1954, 14 pp., 32 fig.

Experiments on 11 types of commercial hardboard made by three companies showed important differences in the amount of moisture absorption and dimensional change during conditioning at different humidity levels. The differences occurred not only for different types of hardboard from a given company, but also for the same products from different companies. The equilibrium moisture content at a given relative humidity and temperature was approximately 50–75% of the corresponding value for wood. With few exceptions each company's board exhibited differences in linear expansion with respect to the original machine direction of the board. The report contains numerous graphs of the relation between moisture absorption and dimensional change. [F. D. C. Tech. Bul. V. 4, No. 22]

Barkers and Barking—Chemical

Wilcox, Hugh. Some results from the chemical treatment of trees to facilitate bark removal. *J. Forestry* 52, no. 7:522–5 (July, 1954); *cf.* B. I. P. C. 24:696.

Some of the results of experiments carried out at the State University of New York, College of Forestry on chemical debarking of living trees are reported. The response of different species to different chemicals; effect of varying concentrations and formulations of arsenic, types of girdles, and time of treatment; distribution of arsenic after treatment; arsenic content of pulp; anatomical features of peeling; and effect on wildlife are discussed. [Bul. Pap. Chem. V. 24, No. 12]

Wilcox, Hugh, Czabator, Felix, and **Girolami, Guido, Seasonal variations in bark-peeling characteristics of some Adirondack pulpwood species.** *J. Forestry* 52, no. 5:338–42 (May, 1954); *cf.* B. I. P. C. 24:89.

Results of experiments on the chemical debarking of trees which were carried out at the State University of New York, College of Forestry are reported. A tool for measuring bark-peeling resistances is described which was devised for testing the peeling of trees during the natural peeling season and for evaluating the effectiveness of chemical treatments to induce bark separation. These two factors were determined for red spruce, yellow birch, white birch, big-tooth aspen, white ash, beech, red maple, and sugar maple. [Bul. Pap. Chem. V. 24, No. 12]

Lignin

Phillips, E. W. J. Influence of leaf activity on the composition of the wood cell wall. *Nature* 174, no. 4419:85–6 (July 10, 1954).

Clarke (*cf. Nature* 135:910 [1935]) discovered that the phloroglucinhydrochloric acid stain revealed a relationship between fiber-wall composition and strength of British ash (*Fraxinus excelsior*); later experiments with other hardwoods demonstrated the applicability of this relationship and tween temperate and tropical species. The brought to light a marked difference bepresent author presents evidence that the controlling factor in lignification (in the botanical sense) of the fiber wall is the illumination received by the leaves. In English ash, the springwood zone (which is formed before the leaves have expanded) of each annual ring consistently gave a poor lignin reaction irrespective of the degree of lignification in the remainder of the ring. The greater lignification of tropical timbers is attributed to the exposure to more adequate solar illumination in the tropics. 1 figure and 3 references. [Bul. Pap. Chem. V. 24, No. 12]

Machinery—Chippers

Arend, J. L., Smith, R. N., and Ralston, R. A. Tests of a portable wood chipper in utilizing logging residue and in disposing of brush. *U. S. Dept. Agr. Forest Service.* Lake States Forest Exp. Sta. Paper no. 30:37 p. (January, 1954).

To investigate the possibilities of portable wood chippers in the field of forest management, a co-operative study, consisting of a series of performance tests utilizing logging residue from pulpwood operations as well as roadside brush, was made in Lower Michigan during 1953. Chipping performance tests were made, using oak-, aspen-, and pinewood, to determine production rates, operational costs, general adaptability, and portability of the chipper for slash and brush disposal and utilization operations. The wood material was separated by random lengths into three general top diameter classes—0–1, 1–4, and 4–6 inch. Two variations of the same model portable chipper, differing mainly in number of knives, cutting speed, and size of feeding hopper were used. The first machine had eight cutting knives operating at a cutting speed of 1500 r.p.m. The modified model had 12 cutting knives operating at a cutting speed of 2200 r.p.m. A 31-horsepower motor was used on both models. It is concluded that the low production costs relative to standard pulpwood should make it possible to market chips from sticks 1–4 inches in diameter which are currently being left in the woods on most pulpwood operations, if the objectionable features of lack of uniformity, high proportion of bark and leaves, mixture of species, and uncertainty of supply can be minimized. [Bul. Pap. Chem. V. 24, No. 12]

Impregnation

Teruo Goto and Shigeru Kajita (Kyoto Univ.). Impregnated woods. I. Wood treatment with low condensation phenol resins. *Wood Research* 1953, No. 11, 29–41.

Wood treated with a 16% resin soln. gave the highest anti-shrinking effect, but that with 20% soln. had the most effect in resin forming on the wood. The anti-shrinking effect was the same under the

curing conditions examd. II. The thiourea resin. Koichi Nishimoto and Yukio Konishi (Kyoto Univ.). Ibid. No. 10, 22–32. —The relation between the pH of thiourea-HCHO resin and the amt. of NH_4Cl added was similar to that between the pH of a weak base and the amt. of strong acid added as shown by Rosenblum (Acid-Base Indicaters, p. 26 (1937)). The curing time of thiourea resin was 23 min. at 105° and 9 hrs. at 80° at 35% resin content, and 26 min. at 105° and 7 hrs. at 25%. Thiourea resin solns. of various concns. were absorbed much more than H_2O by the wood and a 25% resin soln. had the greatest absorption ratio (28%). Wood treated with 25% resin soln. showed the greatest effects on waterproofing and antiswelling. Koichi Nishimoto. [Chem. Abs. V. 48, No. 13]

Utilization

Martin, J. S., Kingsbury, R. M., McGovern, J. N., and Lloyd, R. A. Utilization of white pocket Douglas fir: pulping and chemical conversion. *Forest Products Lab. Bull.* No. 1961, 1–12 (1953).

In logging old-growth Douglas fir areas, 5–60% of the wood is left on the ground because of "white pocket" decay (WP) caused by *Fomes pini*. Chem. Analysis and d. show the damage to be less severe than visual inspection indicates. All the wood constituents are destroyed with about equal intensity. Pulps are made from Douglas fir in various stages of WP to det. its effect on pulp quality. Sulfate pulp shows a slight decrease in burst and slight increase in tear strength with increasing amts. of WP. With severe WP both burst and tear are lowered. A considerable amt. of WP can be present without loss in yield and without great loss in strength. In neutral sulfite semichem. (NSSC) and sulfate semichem. (SSC) pulps, WP does not affect the yield under mild pulping conditions, but under severe pulping conditions the yield is about 5% lower for wood with advanced WP. Pulp strengths are not seriously affected by WP. Pulping Douglas fir with neutral sulfite reagents requires large amts. of chem. and fiberizing energy. SSC pulps can be produced economically. Corrugating and liner boards of satisfactory quality except for stiffness can be made from both NSSC and SSC pulps. Pulps made at higher yields may require blending with stronger pulps to meet specifications. Douglas fir in intermediate stages of WP are made into textile-grade rayon pulp by the prehydrolysis-sulfate process. WP does not affect significantly the production of wood sugar from Douglas fir except that the friable nature of advanced WP would require changes in handling procedures. R. D. Ziegler. [Chem. Abs. V. 48, No. 11]

Lewis, Harry F. Problems affecting the wider use of wood as a technical raw material. III. Hardboard production and bark utilization. (Inst. Paper Chem., Appleton, Wis.). Paper Ind. 36, 55–7 (1954); cf. C. A. 48, 5490b.

The following topics are treated very briefly: The Masonite, Chapman, and Novoply processes for board production, the Presto-log briquetting process, the utilization of various barks (especially redwood bark), the control of insects and Microorganisms, and reforestation and genetics. [Chem. Abs. V. 48, No. 11]

Wood Drying Committee Newsletter

THE COST OF DRYING LUMBER IN SMALL ELECTRIC KILNS—from Technical Note No. 20, Division of Forestry Relations, Tennessee Valley Authority, by G. H. Fechner, Condensation by Paul H. Lane, Staff Forester, Forest Utilization Section, TVA.

Electrically heated lumber dry kilns are manufactured in several European countries. A high frequency kiln has been operating in New England since 1950 but development of electric kilns in the United States has been slow.

TVA in cooperation with the U. S. Forest Products Laboratory has investigated the feasibility of drying lumber at small wood-using plants with electrically heated, cross circulation kilns. Two such kilns are successfully operating on a commercial basis. One is located in Knoxville, Tenn.,[1] the other in Bryson City, N. C.[2] These kilns were designed to meet the needs of the small shop operators. Kiln buildings and equipment are of conventional design except that drying air is heated by electric fin-strip units and humidity is provided by electric immersion heaters in open water tanks. The cost of electric energy (heating and demand charge) for drying about 15 charges of lumber at each of the kilns is summarized below.

Tennessee Kiln: Capacity about 3,500 board feet, dries lumber primarily for furniture manufacture. Drying schedules used are generally moderate. Most lumber is previously air seasoned. Based on the local rate of 0.6 cents per kilowatt hour for power and one dollar per kilowatt of demand, the average drying cost of 14 charges of 4/4 lumber was $9.71 per MBF. Average moisture content difference from beginning to end of the run was 13.4 percent; average drying time, 104 hours. Power was consumed at the rate of 1,121 KWH per MBF; average volume per charge was 2,591 board feet. The cost range was from $5.66 for southern yellow pine (M. C. difference 8.0 percent; drying time 47 hours) to $16.01 for redgum (M. C. difference 34.2 percent; drying time 166 hours). Data are summarized by species in Table 1.

North Carolina Kiln: Capacity about 6,000 board feet. This kiln is used primarily to dry material going into interior trim and other millwork. Rather severe drying schedules are used. Most of the lumber is cut on the company sawmill and air seasoned for a period before entering the kiln.

Based on the local rate of 0.8 cents per KWH for power and $87.50 per month for demand, cost of drying sixteen 4/4 loads averaged $5.60 per MBF. Average moisture content difference was 21.9 percent; average drying time, 63 hours. Power consumption was 518 KWH per MBF; the average load contained 5,432 board feet. The range of costs was from $2.83 for air-dry southern pine to $14.85 for green southern pine.

Unit costs are somewhat lower than those found in the Knoxville kiln even though the electricity rates are higher. Two factors are responsible. The schedules applied to the lumber loads were rather severe. Secondly, the volume of lumber in the kiln was about twice that of the Knoxville kiln. This not only helps reduce the unit demand charge through increased monthly production, but it also helps reduce the kiln wall radiating area per MBF. Comparative radiating wall area was 436 and 319 square feet per MBF, based on the average kiln volume. Drying costs are summarized by species in the table below.

(Continued on page 37-A)

[1] Jolly, W. W. and Stanfield, J. H., "An Experimental Electric Kiln for Drying Lumber," *Southern Lumberman* 178:88, 90, 92, 1949.

[2] Lane, Paul H., *A Small Electrically Heated Dry Kiln*, TVA Division of Forestry Relations, Technical Note No. 12, Norris, Tennessee, 1952.

Table 1.—ELECTRICAL DRYING COSTS, 4/4 LUMBER

Species	Observations Number	Moisture Content Difference Percent	Power Consumption per MBF Kilowatt Hours	Heating Costs		
				Power	Demand* Dollars	Total
Southern Pine	3	17.6	945	5.82	1.83	7.65
Black Walnut	5	7.3	1,077	6.43	3.00	9.43
Red Oak	2	13.5	832	5.05	2.52	7.57
Beech—Maple	3	13.4	1,326	8.03	3.74	11.77
Redgum	1	34.2	1,839	11.04	4.97	16.01

*Prorated on basis of number of like charges possible during 30-day month.

Table 2.—ELECTRICAL DRYING COSTS, 4/4 LUMBER

Species	Observations Number	Moisture Content Difference Percent	Power Comsumption per MBF Kilowatt Hours	Heating Costs		
				Power	Demand* Dollars	Total
Southern Pine	12	23.4	523	4.18	1.41	5.59
Black Walnut	1	9.9	360	2.88	1.17	4.05
Red Oak	2	19.0	524	4.19	1.60	5.79
Chestnut	1	22.5	600	4.80	2.08	6.88

*Prorated on basis of number of like loads per 30-day month.

ALABAMA
W. T. Smith Lumber Co., Chapman

ARKANSAS
The Crossett Co., Crossett
Dierks Forests, Inc., Mountain Pine
Southern Lumber Co., Warren

CALIFORNIA
California Redwood Association, San Francisco
L. J. Carr & Co., Sacramento
Crane Mills, Corning
Ivory Pine Co., Dinuba
National Wood Treating Corp., Oroville
Scott Lumber Co., Inc., Burney
Tarter, Webster & Johnson, Stockton
Winton Lumber Co., Martell
E. K. Wood Lumber Co., San Francisco

GEORGIA
Southern Wood Preserving Co., Atlanta

IDAHO
Potlatch Forests, Inc., Lewiston

ILLINOIS
The Dean Company, Chicago
General Electric, Illinois Cabinet Plant, Rockford
Greenlee Tool Co., Rockford
Edward Hines Lumber Co., Chicago
Illinois Interior Finish Co., Chicago
Johnson & Carlson, Chicago
Masonite Corp., Chicago
Mattison Machine Works, Rockford
Pressed Steel Car Co., Inc., Chicago
Sherwin–Williams Co., Chicago
Steger Furniture Mfg. Co., Steger

INDIANA
The Dunbar Furniture Mfg. Co., Berne
National Homes Corp., Lafayette
The Wood-Worker & Veneers and Plywood, Indianapolis

IOWA
Curtis Co. Inc., Clinton

LOUISIANA
A. J. Hodges Industries, Inc., Shreveport
Louisiana Long Leaf Lumber Co., Fisher

MARYLAND
National Store Fixture Co., Inc., Odenton
J. I. Wells, Salisbury

MASSACHUSETTS
Draper Corp., Hopedale
Heywood–Wakefield Co., Gardner
A. G. Spalding & Bros., Inc., Chicopee

MICHIGAN
Baker Furniture, Inc., Grand Rapids
The Dow Chemical Co., Midland
Everett Piano Co., South Haven
The Lloyd Manufacturing Co., Menominee

MINNESOTA
Mereen–Johnson Machine Co., Minneapolis
Rilco Laminated Products, Inc., St. Paul
Wabash Screen Door Co., Minneapolis

MISSOURI
Monsanto Chemical Co., St. Louis

NEVADA
Vaughn Millwork Co., Reno

NEW YORK
American Defibrator, Inc., New York
Behr-Manning Corp., Troy, N. Y.
Borden Co., New York
Peter Cooper Corps., Gowanda
Oval Wood Dish Corp., Tupper Lake
Reichhold Chemicals, Inc., White Plains
United States Plywood Corp., New York

NORTH CAROLINA
The Champion Paper & Fiber Corp., Canton
Deluxe Saw & Tool Company, High Point

OHIO
The Baker Wood Preserving Co., Columbus
The Baldwin Co., Cincinnati
Coe Manufacturing Company, Painesville
The Kirk & Blum Mfg. Co., Cincinnati
Moraine Box Company, Dayton

OREGON
Cascades Plywood Corporation, Portland
Forest Fiber Products Co., Forest Grove
J. Neils Lumber Co., Portland
Oregon Lumber Co., Baker
West Coast Lumberman's Assn., Portland

PENNSYLVANIA
Blaw–Knox Company, Pittsburgh
Firth Sterling Steel & Carbide Corp., Pittsburgh
Koppers Company, Inc., Pittsburgh
Perkins Glue Co., Lansdale
United States Steel Homes, Inc., Harrisburg
Wood Metals Industries, Inc., Kreamer, Snyder County

SOUTH CAROLINA
Lightsey Brothers, Miley

TENNESSEE
E. L. Bruce Co., Memphis
Chapman Chemical Company, Memphis
Memphis Hardwood Flooring Co., Memphis
Nickey Bros., Inc., Memphis

TEXAS
Wm. Cameron & Co., Inc., Waco
Kirby Lumber Corporation, Houston

VERMONT
Fyles & Rice Co., Inc., Bethel

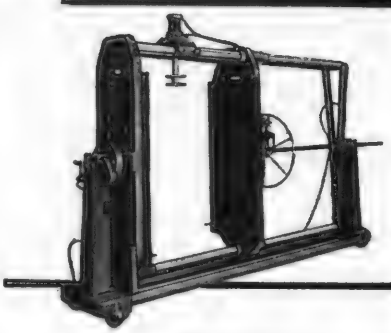
WASHINGTON
American Marietta Co., Seattle
Deer Park Pine Industry, Inc., Deer Park
Douglas Fir Plywood Association, Tacoma
The Long–Bell Lumber Co., Longview
Simpson Logging Co., Shelton
Weyerhaeuser Timber Co., Tacoma

WISCONSIN
The Buckstaff Co., Oshkosh
Harnischfeger Corp., Port Washington
Marathon Corp., Rothschild
Mosinee Paper Mills Co., Mosinee
D. J. Murray Mfg. Co., Wausau
Paine Lumber Co., Oshkosh

ALASKA
Ketchikan Spruce Mills, Ketchikan

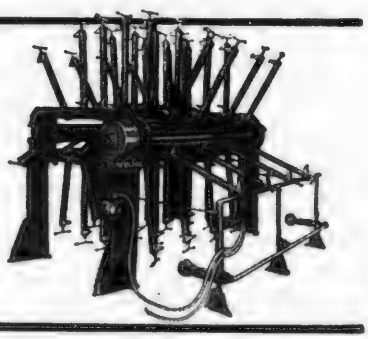
CANADA
British Columbia Lbr. Mfrs. Assn., Vancouver, B. C.
Canadian Forest Products Limited, New Westminster, B. C.
Canadian Siempelkamp Ltd., Hamilton, Ont.
Dominion Electrohome Industries, Ltd., Kitchener, Ont.
The Knight Mfg. & Lbr. Co. Ltd., Meaford, Ontario
MacMillan & Bloedel Limited, Nanaimo, B. C.
A. S. Nicholson & Son, Ltd., Burlington, Ont

Clamps



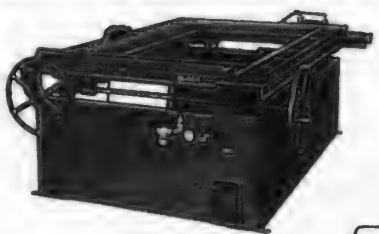
CASE CLAMPS

Massive tubular supports are mounted as fixed preloaded beams that will remain rigid and true, insuring accurate work under any load. No cast iron is used in any strain receiving member. Convenient controls and a powerful brake make operation easy and accurate. Write for Bulletin 11-J.



CLAMP CARRIERS

Black Clamp Carrieres are made in a practically unlimited range of sizes with respect to the number and width of sections and number, length and style of clamps. Carriers are made entirely of arc-welded and fabricated steel, providing an unbreakable frame and permitting flexibility of design. Write for Bulletin 11-K.



SASH AND FRAME CLAMPS

Black's two-way pneumatic clamps are mounted on a rigid, solid steel base with all controls conveniently grouped at the front. Valves and air supply lines are protected from damage by this base. Black clamps have been tested under production conditions, and proven to be fast, efficient and reliable. Write for Bulletin 11-M.

"If its gluing equipment—we have it"

THE BLACK BROTHERS CO., INC. 810 9th ST., MENDOTA, ILLINOIS

(Continued from page 9-A)

the trade press; and organization of sessions on this subject at national and sectional association and society meetings. These could include symposiums on the contributions of technically-trained men. Industry principals should be induced to visit colleges and meet faculty members and students, thus becoming more familiar with what the schools have to offer. Similarly, students and faculties should be invited to their operations; and to attend and participate in technical and other types of meetings of industry. It was recommended that the FPRS Committee on Employment study ways and means of placing students in summer or other part-time work.

III. *How to interest qualified young men.* The problems are, first, to interest students of high school and college level to inquire about possibilities; and second, to get the proper information into the hands of advisors. Competition with other fields, particularly engineering, is keen, and salaries and job opportunities available to properly trained men are often determining factors. Major recommendations included: 1) Dissemination of information through established channels, particularly on the high school level; preparation of a brochure pointing out the importance of the forest products industries in the economy of the nation, opportunities for employment, and the qualifications required. 2) Publish additional, more specific information for limited distribution to FPRS members and for answering inquiries. A leaflet listing schools offering specialized training in forest products was suggested. 3) Literature should also be made available in quantity to industry firms willing to distribute it, at their cost, over their mailing lists. 4) Encourage forestry schools to distribute their own brochures on the local level. 5) The tremendous potentialities of advertising made available through public spirited firms in magazines, radio, TV, film strips, movies, etc. was recognized.

WOOD DRYING NEWSLETTER

(Continued from page 35-A)

Summary

A study of electric power and demand costs for drying 4/4 lumber showed averages of $9.71 and $5.60 per MBF at two electrically heated kilns. The primary factor affecting the greater cost was the drying time; that affecting the lesser cost was moisture content difference from beginning to ending of drying. An important item of electrical drying costs is the demand charge, which varies inversely with monthly production. It can be somewhat reduced by judicious operation. The costs of drying with electricity are somewhat higher than available figures for other methods of heating, even in this area of low-cost power. In contrast to the rather high cost of heating with electricity, the electrical kiln offers a low initial investment and low operating expense. It is a convenient method of drying for the small shop operator.

FPRS News-Digest, Continued

SHORT COURSES

Course in Statistical Methods

The Institute of Statistics at North Carolina State College is sponsoring a nine day intensive training program in Statistical Methods for Research Workers in Industry and the Physical Sciences starting January 22, 1955 and running daily through January 30, 1955. The course is designed to make available to research workers in industry and the physical sciences the new and powerful statistical techniques of data analysis and experimental design. Guest lecturers will include W. J. Youden, National Bureau of Standards; Carl A. Bennett, General Electric Company; and Cuthbert Daniel, Statistical Consultant, New York City.

Registration fee, $100.00. For information write to Institute of Statistics, N. C. State College, Box 5457, Raleigh, North Carolina.

Gluing Short Course

"Too often glues are blamed for poor bonds when in reality a faulty gluing technique is the cause," says Professor Alfred H. Bishop, associate professor of forest utilization at the State University College of Forestry in Syracuse, N. Y., in reminding that the College's short course in gluing will be held January 24–29. The fee for the course which is limited to 12 students is $75. Write Prof. Russell C. Deckért, Forest Utilization Department, State University College of Forestry, Syracuse 10, N. Y.

New Gluing Developments Course will be held in the School of Forestry at North Carolina State College Jan. 24–28. The course will include such techniques as chip core, radio frequency, strip core, testing, new glues, trouble shooting, and quality control. It will be conducted by the N. C. extension division and school of forestry in cooperation with the Southeastern Forest Experiment Station, the Hardwood Plywood Institute, the Southern Furniture Mfgr's Ass'n., and the U. S. Forest Products Laboratory. For further information, write Richard J. Preston, Dean, School of Forestry, N. C. State College, Raleigh, N. C.

FPRS SCOREBOARD

by Bob Smith

Every year we lose about 10% of our membership through resignation, non-payment of dues, etc. Fortunately, this percentage has been going down in recent years; however, as can be seen from the table below, it is quite disheartening to reach a good membership figure in mid-year, only to have to readjust our sights later in the year. On the brighter side, I feel that efforts are paying off in our quest for new members. We have netted 300 members over 1953 and are still climbing higher. Since the count of Nov. 19 was taken we have added 54 new members to raise the current total membership figure to 2,586. With more student and voting member campaigns being continually pushed, the membership growth will go steadily upward.

Take at look at the membership figures listed for Nov. 19 in the table below. The largest sections lost the most members. However, although they lost the most members, I feel that they will find it the easiest to replace their losses. We have fine men in the membership chairmen positions—yet they cannot do all the work. You as an individual member can be very helpful by sending in prospect names to either your section membership chairman or to me. Incidently, now is a good time to bring in a new member. As you know, our new fiscal year starts April 1, 1955. However, we will be very happy to place the names of any new members on our rolls between now and April. Thus they will be started on their services a full month or two before their membership officially goes into effect!

FPRS TEAM STANDINGS

	Members 1953	Members 11/19/54	Wgtd. Avg.
Inland Emp.	44	62	.356
No. Calif.	93	114	.208
Northeast	405	488	.203
East Canada	129	156	.194
Great Lakes	167	199	.181
Ohio Valley	82	95	.144
Pac. N'west	299	334	.113
Upper Miss.	80	90	.111
Pac. S'west	48	53	.092
Midwest	306	329	.073
Car.–Chesapeake	204	216	.056
Deep South	140	147	.047
Fla.–Ga.–Ala.	86	85	---
Foreign	193	164	---
Totals	2,276	2,532	.127

NAMES IN THE NEWS

Retired Navy Officer Joins Radio Receptor Co.

Admiral J. J. ("Jocko") Clark, U. S. N. (retired), as a v. p. was announced by Ludwig Arnson, pres.

PHOTO HIGHLIGHTS of Northeast Section meeting at New York City, Nov. 4, 5. Pres. Carr addressing his 11th FPRS meeting since last May. Past Pres. Geo. Garratt, toastmaster, and luncheon panel speakers. Session I speakers Bill West, Bill Wilkins, Don Saunders, Earl Stivers, Bob Seidl, and Paul McCormack.

SECTION OFFICERS meet: Seated, V. chairman, Saunders, Chairman Charlie Lockard, Sec.–Treas., Bill Delmhorst. Standing, Newell Norton, Eric Anderson, Don Pierce, Paul Graham, and Jim Sechrist. Right: Session speakers on "What's new in wood processing."

N.E. EMPLOYMENT committee meets: Clarence Van Epps, Fred Wangaard, Nat'l Employment chairman Newell Norton, Bill Nearn, and Ray Hoyle.

N.E. MEMBERSHIP chairman Paul Graham, receives application for membership from R. A. Caughey as national membership chairman Frank Parrish and Pres. Les Carr look on.

PROF. HARRY RICH assisted by Paul Graham and Howard Gatslick leads wood drying discussion group.

Founded in 1922, Radio Receptor manufactures electronic equipment for communications, radar and navigational applications, as well as dielectric heating equipment.

Swiss Chipboard Men Tour States

Two European chipboard authorities toured this country in December with D. N. Copp and R. O. Wilson, Wilco Machine Works, Inc., Memphis, Tenn. They were Rene Fischer, Lausanne, and Andrew Brand, Tavannes, Switzerland. Both are principals in Fibrexa, Nauchatel, Switzerland, a firm which has developed a process for the manufacture of a flake board that has the structural and appearance characteristics of lumber. Brand is director of a company at Tavannes which produces "Tavapan" a board using the Fibrexa process with a Siempelkamp press.

DON STOHLMAN addresses dinner guests at Dec. 1–2 Great Lakes Meeting at Grand Rapids, Mich.

OLIVER MACHINERY COMPANY was host to one of the plant tours.

AMONG SESSION SPEAKERS were: George McNew, A. Brant Inc.; Kenneth Deal, Rapid Furniture Shops; Harry Klepser, Grand Rapids Store Equipment Co.; John McPhee, Baker Furniture Co.; Gaylord Reeves, American Seating Co.; Robert Reed, John Widdicomb Co.; and William L. Rabinstein, Kroehler Mfg. Co.

Wilco, U. S. Siempelkamp representative, maintains an experimental laboratory to prove out various chipboard processes.

←National Starch Products Promotes Men

R. A. Bintz, National's Plainfield, N. J. plant manager has been promoted to the position of Assistant Director of Manufacturing. At the same time, James L. Edwards, plant superintendent at Plainfield, succeeds Bintz as plant manager. Bintz joined National in 1939 and has been plant manager at Plainfield since 1947. Edwards, before becoming plant superintendent in 1946, served in various capacities in the Plainfield plant.

WOOD PRESERVATIVES

for every purpose

- DECAY!
- STAIN!
- TERMITES!
- MOISTURE!

WOOD TREATING

W C T C

SALES AGENTS

MONSANTO CHEMICAL CO.
SANTOPHEN 20 (Pentachlorophenol)

WYANDOTTE CHEMICAL CO.
NOXTANE (Sap Stain)

EFURD MACHINE & WELDING CO.
HURRICANE
Peelers, Framers, Trams, etc.

WOOD-TREATING Chemicals Co.
5137 Southwest Ave.
St. Louis 10, Mo.

FPRS News-Digest, Continued

Current Literature

Forest Statistics for the Hill Country of Ohio. Forest Survey Release No. 17. Many sawmills operate in this region and many farmers increase their income by producing fence posts, mine props, and pulpwood.

Forest Statistics for the Glaciated Region of Ohio. Release No. 16. Forest-area and timber-volume statistics include most of the Western and Northeastern areas commonly known as the Ohio Corn Belt and the Dairy Region. Western Ohio forests are not heavily forested. Northwestern Ohio forests are best known for maple syrup and "car blocking." Available: Central States Forest Experiment Station, Columbus, Ohio.

"Pallets and Palletization," a technical handbook describing modern methods of materials handling in manufacturing, ware housing, and transportation operations; is available from the National Wooden Pallet Manufacturers Ass'n., 215 Barr Building, Washington 6, D. C. The booklet starts with an explanation of palletization, the reasons therefore, and how to properly plan for it. It continues with sections on principles of pallet construction, specifications, how to choose and purchase the correct pallet, unit load patterns, and instructions for the use, maintenance, and inspection of pallets. A glossary of terms and list of government specifications are included for reference purposes. $1.00 per copy.

The Kiln-Drying of British Columbia Lumber. J. H. Jenkins and F. W. Guernsey. Bul. No. 111. Result of experience and data secured at the Vancouver Laboratory of the F.P.L. of C., during the past twenty years. Covers: reasons and methods of seasoning wood; moisture relations; factors affecting drying; seasoning defects and their prevention; dry kilns and their equipment; and dry kiln operation. Available: Forest Products Laboratories of Canada, Ottawa, Ontario.

Yellow Cedar (Its Characteristics, Properties, and Uses). R. S. Perry. Bul. No. 114. This bulletin has been prepared to make readily available all pertinent data relative to the occurrence, properties, and uses of yellow cedar.

Facts About the Forests of the Redwood Region. 1954–55 edition. AFPI, Inc. 1816 N St. N. W., Washington 6, D. C. in cooperation with the California Redwood Ass'n. 576 Sacramento St., San Francisco 11, Calif.

Behavior and Control of Understory Hardwoods After Clear Cutting a Piedmont Pine Stand. Station Paper No. 44. E. V. Brender and T. C. Nelson. A study was made in Georgia in a typical cutover pine stand with a hardwood understory to measure the rate of hardwood invasion, the reaction of hardwood species to release, and the effectiveness of cutting, burning, and grubbing as control measures in reducing hardwoods.

Forest Insects (Southern Forest Insect and Disease Reporter) No. 4. Describes current forest insect and disease conditions in Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas. Available: Southern Forest Experiment Station, 2026 St. Charles Ave., New Orleans 13, Louisiana.

Manufacture of Hardboard in the U. S. George G. Marra. (Reprinted from Paper Trade Journal, April 2, 1954) Discusses the rapid growth of the hardboard industry and summarizes its present status. Proposes a classification of processes based on particle types and methods of forming, and presents descriptions of the processes and production capacities for each producing unit, bringing out the basic differences among processes and products. Available from Eri B. Parker, Director, Division of Industrial Research, Pullman, Washington.

Small Sawmill: A Pocket Guide, C. J. Telford. The U. S. Forest Products Laboratory has combined the results of years of sawmill research with practical in-the-field experience to produce a handy pocket guide for operators of small sawmills that is aimed at manufacturing better lumber with less waste and at lower costs. It starts with suggestions on setting up a mill—advises how to lay the sills and husk for a proper foundation, how to support and level the trackway, place the carriage, connect the power unit, and hang and adjust the saw. Once the mill is set up, the guide will help the operator correct such problems as belt slippage, sprung mandrel, chattering saw, scored logs, and teeth or holders out of line. After the mill is in operation, the guide will help in the selections of the proper combination of feed rate, saw speed, and power requirements for a given product, help the operator cut his lumber to proper sizes and handle special sawing problems, such as outsize logs, stringy bark, frozen timber, very hard wood, small knotty logs, and sawing for grade. Copies of Handbook No. 70 may be obtained from Supt. of Documents, Government Printing Office, Washington 25, D. C. for 15 cents.

Palco Literature

The following pieces of literature on the proper utilization of lumber are available without charge from The Pacific Lumber Co., 35 East Wacker Drive, Chicago 1, Ill.: "Bevel Siding—Vertical Grain vs. Flat Grain", "Buying Lumber for the Factory", "Getting Humidity Out of the Home", "Preventing Paint Troubles on House Siding", "Recognizing Assets", "Redwood Core Stock", "Sawmilling at Its Best", "Selling Lumber and Lumber Products", "Screw Holding Properties of Redwood", "Wood vs. Aluminum—Keeping Homes Summer Cool—Winter Warm".

Book Review

Van Groenou, H. Broese; Rischen, H. W. L.; and Van den Berge, J. Wood Preservation During the Last 50 Years 2nd Edition, 1952, A. W. Sijthoff's Uitgeversmaatschappij N. V., Leiden (Holland) 318 pages, illus.

This second edition of the original 1951 publication brings the book up to date. It is a well documented, worldwide review of the subject of wood preservation and should be useful to those with a general or academic interest in wood preservation and particularly to those engaged in research work. Approximately two-thirds of the text deals with the wood deteriorating agencies such as fungi, insects, and marine borers and with a description of wood preservatives and methods of wood preservation, including those of importance as well as those of limited interest and use. The authors, in the remainder of the text, review scientific research in wood preservation in various countries and give special emphasis to research institutions, and to laboratory methods used in evaluation of wood preservatives.

The reviewer has found the text particularly useful for the information it contains on some of the proprietary preservatives used outside the United States, the details of preservative standards in various countries and on the descriptions of laboratory test procedures used by various research organizations. Since the authors call attention to the importance of service tests, cite service data frequently, and mention that service records published in the Proceedings of the American Wood Preservers' Association are studied with interest all over the world, it would have seemed appropriate for them to have included in the discussion of evaluation procedures, some description of the planning and organization of service tests on treated posts, poles, crossties, and similar products.

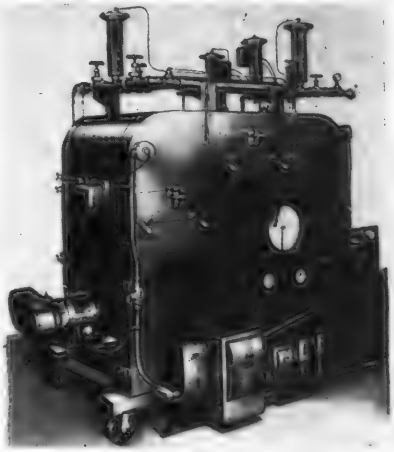
J. O. Blew.

FPRS News-Digest, Continued

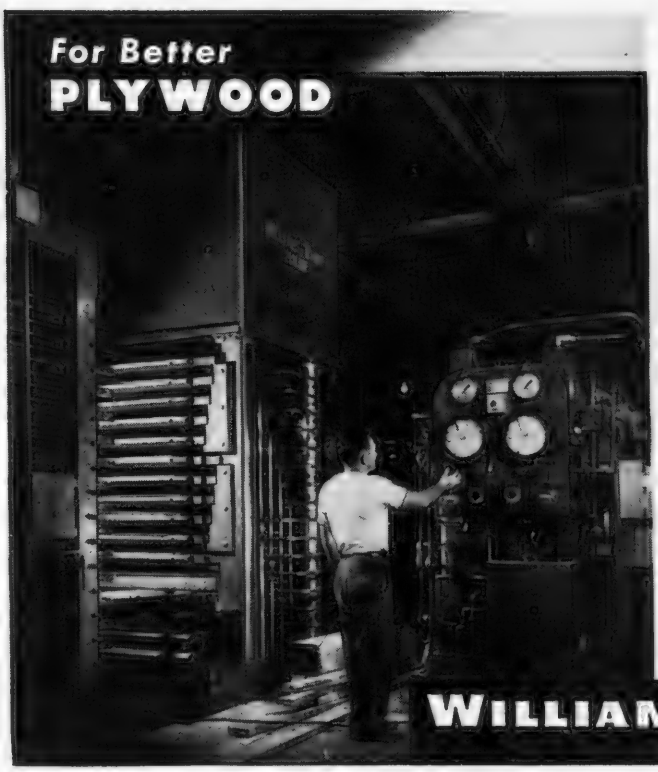
Super-Shaper For Auto Body Wood Mock-Ups. Greenlee Bros. & Co., Rockford, Ill., has developed a special-built, 180″ x 60″ one-piece outsize table, direct electric drive, double spindle shaper for use in body design shops. Many additional applications can be found in pattern and woodworking shops handling large and irregularly shaped pieces of work. Cutters up to 24 inches in length can be used for any shape desired. Vertical adjustment is provided through a screw and spiral gear arrangement. Accidental starts when changing spindles are eliminated by a locking device. In order to speed up knife changes and to give quick stopping of the spindle assembly in any emergency, a fast acting, foot operated spindle brake is provided.

Berry Hydraulic Drives for sawmill carriages are detailed in a new 8-page bulletin. Said to increase production from 10% to 35%, Berry Drives are available as complete "packaged" units, including a pump, motor, cooler and other components. A feature of the bulletin is the Drive Selector which gives the proper drive number for various carriage weights, strokes and lines per minute. Copies of Bulletin SM–1 may be obtained from Berry Div., Oliver Iron and Steel Corp., Oliver Bldg., Pittsburgh 22, Pa.

New Carbide Saw Blade—a new line of low-cost carbide tipped saw blades is offered by the makers of Woodsman carbide tipped blades. One blade is for cross-cutting and ripping featuring alternating scoring teeth followed by a raker tooth in each section. The other is a heavy-duty "rip" with full-throated gullet and strong tooth design for fast, deep cutting. Write North American Products Corp., Box 210, Center Grove Road, Edwardsville, Ill.



New Portable Dryer. C. G. Sargent's Sons Corp., Graniteville, Mass., announces a new, full-size, portable, instrumented, completely self-contained dryer. It is available to industry and university laboratories on a rental, a rental-purchase, or outright purchase basis. It is said to incorporate most known features of research laboratory dryers with the advantage of portability. It uses either steam-heated or electrically-heated air. Another feature: casters which lock securely when dryer is positioned on the job.



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FPRS News-Digest, Continued

Glulam Booklet. "Glulam Arches and Beams, and Timber Roof Trusses," is available from MacKintosh & Truman, Inc., wholesale lumberman, 515 Vance Building, Seattle 1, Wash. This 12-page booklet, illustrated, is a presentation of glued-laminated timber structures which are manufactured by the American Fabricators, Bellingham, Wash. The publication is free and shows typical church, supermarket, school, residential and other construction, including engineering data on glulam sizes.

Process Temperatures Sensed, Transmitted by New Device

A new instrument which accurately measures process temperatures and pneumatically transmits the information to a central recording or controlling station has been announced by the Foxboro Company of Foxboro, Mass. Known as the Model 12A Temperature Transmitter, it is a nonindicating device of the "force balance" type with a calibrated accuracy of ½% of the temperature span and compensated for ambient temperature and barometric pressure variations. Spans ranging from 50° F. to 400° F. are available and can be utilized between the limits of −100° F. and +1000° F.

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Can Do For You:

1. Increase The Heating Value Of Your Wood Scrap!

When reduced to chip form by hogging, wood burns more evenly—gets *all* the heat value possible. Unhogged slabs, trimmings, large pieces, restrict air flow, smother fire, result in inefficient combustion.

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Processing wood scrap with a Williams Hog, for resale in the form of wood flour or sawdust, assures more uniform grinding and sizing—much lower labor costs—reduced power requirements.

3. Reduce Handling Cost As Much As 75%!

One man firing wood in chips can handle the same tonnage as would require three men if fuel scrap remained in awkward lengths and pieces that necessitate individual handling.

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Williams equipment will actually pay for itself in a few months, then continue to produce extra profits for many years. Investigate now!

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No. E 157—Progressive North Carolina furniture manufacturer needs top quality foremen at once. Machine room, sanding room, and superintendent for one of the largest firms in the business. Top pay for the right man. Do not apply unless you feel that you have a definite future in furniture.

No. E 158—Good sales territory in Great Lakes area representing glue company has opened up. The firm is well established in the area and product requires little missionary work. Young man with wood working experience and an understanding of glues and their application preferred. Actual sales experience is desirable but not necessary.

No. E 159—Southern hardwood dimension plant has opening for assistant production manager. Young man with college wood technology degree preferred. Experience in lumber manufacturing desirable but not necessary.

No. E 160—Well-known Chicago firm has opening for wood finishing technician or quality control engineer capable of specifying and testing finishes for high grade wood furniture. Knowledge of organic finishes for metal also desirable. (Salary open.)

No. E 161—Development and production engineering, for midwest plastic laminate firm working in melamine and phenolic resins, polyester and fiberglass. College graduate or equivalent experience in early thirties with moderate woodworking experience. Good starting salary for man willing to work hard and prove worth. Located in beautiful lake city.

Employment Wanted

No. 240—Forestry major graduating December from Iowa State College seeks position in the field of utilization or promotion. Courses taken include: logging, lumber manufacture, wood utilization, timber preservation, wood technology, and forest products. Veteran. Age 31.

No. 241—I offer you forceful, capable services as an independent executive or administrative assistant in veneer, plywood, flush-door, and/or furniture mfg. company, in return for reasonable future prospects. Young forest products engineer (35 years) with notable, 10 years experience as plant supt., tech. director, and practical mill training. Currently located in Northwest.

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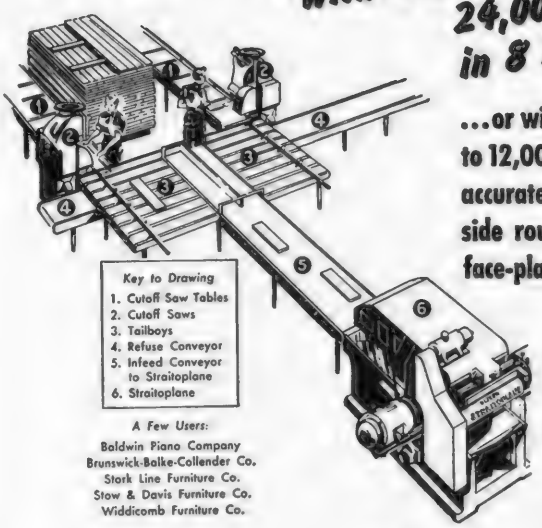
with 3 men can process 24,000 ft. of lumber in 8 hours

...or with 2 men from 6,000 ft. to 12,000 ft. in one day. Stock is accurately sawed to length, one side rough surfaced, other side face-planed to correct dimension



Key to Drawing
1. Cutoff Saw Tables
2. Cutoff Saws
3. Tailboys
4. Refuse Conveyor
5. Infeed Conveyor to Straitoplane
6. Straitoplane

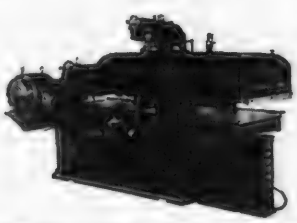
A Few Users:
Baldwin Piano Company
Brunswick-Balke-Collender Co.
Stork Line Furniture Co.
Stow & Davis Furniture Co.
Widdicomb Furniture Co.

• Using an "Oliver" conveyorized layout, two men running two Cutoff Saws and one man to tend the Straitoplane can turn out up to 24,000 ft. a day. With one man at a Cutoff Saw, up to 12,000 ft. a day.

• This system is most efficient for processing rough lumber from bunk through surfacer. It gives flat, uniform stock. Cuts manpower, speeds production. Avoids unpiling and repiling on trucks.

• The "Oliver" layout can be changed to meet your special needs. If you produce 4,000 ft. or more a day, get all the facts on this Conveyorized Rough Mill system.

"Oliver" automatic Cutoff Saw makes up to 43 cuts a minute. Hydraulic operated. Has wide capacity. Makes cuts without .005 inch variation.



Straitoplane removes warp or wind from stock, rough surfaces one side, face-planes other in one operation. Takes stock to 36" wide, ½" to 6" thick, from 16" up in length. Feed: 20' to 60' or more a minute. Processed stock is straight, flat, uniform.

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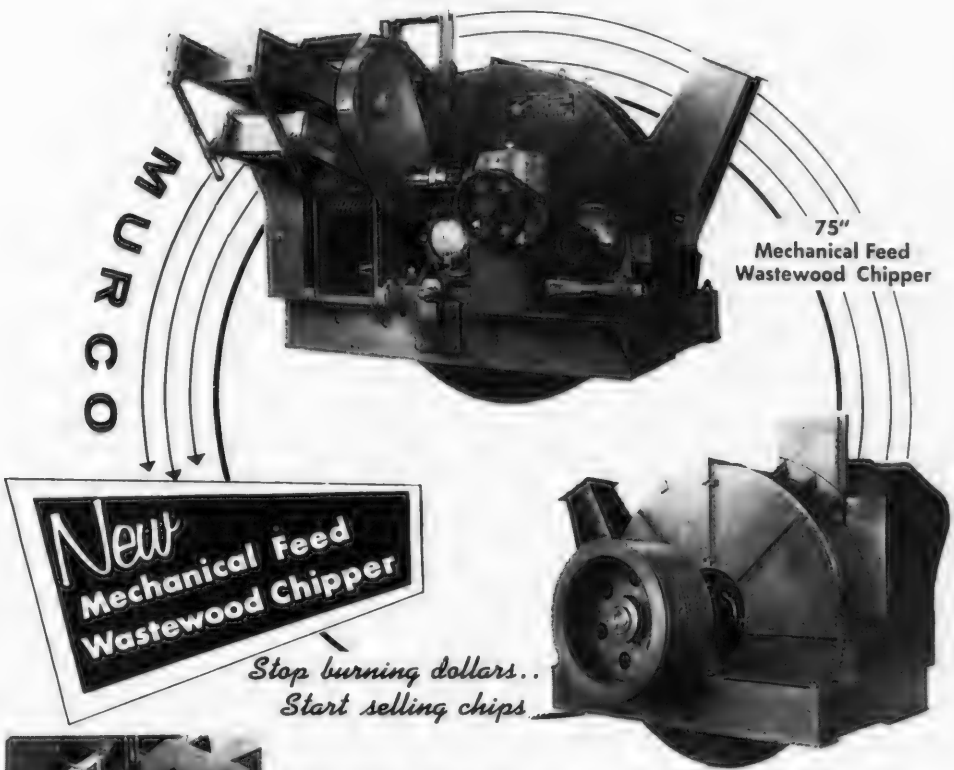

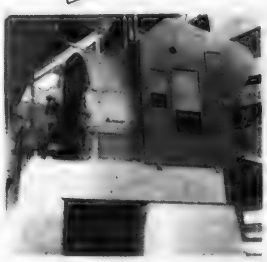

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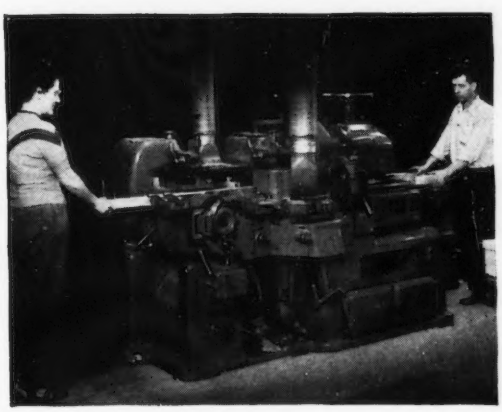

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March 18, 1953

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Our operators find this Mattison No. 276 very easy to set up, due to the accessibility of all the adjustments and controls. Vertical and cross adjustments of the cutterheads are made positively and quickly, and the hand locking wrenches which are attached to the machine simplify setting of the guides. Another feature is that it "stays put", which is no doubt due to the rigid construction, precision manufacture, and advanced engineering design. The outboard bearings eliminate vibration in heavy cuts, and we believe that any high speed moulder spindle should have an outboard bearing.

We are confident that this machine will continue to perform efficiently for a great many years.

Yours very truly,

IMPERIAL FURNITURE COMPANY

A. F. Christy

A. F. Christy
Plant Manager

- Imperial Furniture Company's reputation for building a high quality line of tables is in a good measure due to precise fabrication methods which insures consistently accurate results and proper fitting of all parts. Mr. A. F. Christy, Plant Manager of Imperial, has been around the woodworking industry for a good many years and knows what he wants and has to have in the way of production and accurate results. The above letter telling of his experience with the Mattison 276 Moulder is an example of what this machine is doing for a good many others. For complete information on the Mattison 276 High Speed Electric Moulder, ask us to send you our latest free circular.

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